Forestry Canada Forêts Canada

The Canadian Forestry Service Air Pollution Program and Bibliography

P.A. Addison and P.J. Rennie

Information Report DPC-X-26
Forest Science Directorate

The Canadian Forestry Service

The Canadian Forestry Service is the main focus for forestry matters in the federal government. It provides national leadership through the development, coordination, and implementation of federal policies and programs to enhance long-term economic, social, and environmental benefits from the forest sector for Canadians.

The service is a decentralized organization with six regional forestry centres, two national research institutes, and seven regional sub-offices located across Canada. Headquarters is located in the National Capital Region, in Hull, Quebec.

In support of its mandate, the Canadian Forestry Service carries out the following activities:

- Administers forest development agreements negotiated with the provinces
- Undertakes and supports research, development, and technology transfer in forest management and utilization
- Compiles, analyzes, and disseminates information about national and international forest resources and related matters
- Monitors disease and insect pests in Canada's forests
- Provides information, analyses, and policy advice on economics, industry, markets, and trade related to the forest sector
- Promotes employment, education, and training opportunities in the forest sector
- Promotes public awareness of all aspects of the forest sector.

The service interacts regularly with provincial and territorial governments, industry, labor, universities, conservationists, and the public through such bodies as the Canadian Council of Forest Ministers, the Forest Sector Advisory Council, the Forestry Research Advisory Council of Canada, the Canadian Forest Inventory Committee, the Canadian Committee on Forest Fire Management, the Canadian Interagency Forest Fire Centre, and regional consultative committees. The service is also active in international forestry agencies such as the International Union of Forest Research Organizations and the Food and Agriculture Organization, as well as in technical and trade missions.

Le Service canadien des forêts

Le Service canadien des forêts est l'organisme principal en matière de foresterie à l'intérieur du gouvernement fédéral. Chef de file sur le plan national, il assure la préparation, la coordination et la mise en œuvre des politiques et programmes fédéraux dans le but d'améliorer les avantages économiques, sociaux et environnementaux à long terme offerts aux Canadiens par le secteur forestier.

Le Service est une organisation décentralisée: six centres de foresterie régionaux, deux instituts de recherche nationaux ainsi que sept sous-bureaux régionaux sont répartis dans tout le Canada. Le siège social est établi dans la région de la Capitale nationale, à Hull (Québec).

Pour remplir son mandat, le Service canadien des forêts assume les tâches suivantes:

- il administre les accords de développement forestier conclus avec les provinces
- il entreprend et appuie la recherche, la mise au point et le transfert technologique dans le domaine de la gestion et de l'utilisation des forêts
- il rassemble, analyse et diffuse de l'information sur les ressources forestières nationales et internationales et les domaines connexes
- il fait des relevés des maladies et des insectes ravageurs des forêts canadiennes
- il fournit de l'information, des analyses et des conseils (quant aux politiques) concernant l'économie, l'industrie, les marchés et le commerce reliés au secteur forestier
- il favorise les occasions d'emploi et de formation universitaire et technique dans le secteur forestier
- il encourage les Canadiens à prendre conscience de tous les aspects du secteur forestier

Le Service entretient des rapports sur une base régulière avec les gouvernements provinciaux et territoriaux, l'industrie, le monde du travail, les universités, les environnementalistes et le public par l'entremise d'organismes comme le Conseil canadien des ministres des Forêts, le Conseil consultatif du secteur forestier, le Conseil consultatif de la recherche forestière du Canada, le Comité de l'inventaire des forêts du Canada, le Comité canadien de la gestion des incendies de forêt, le Centre interservices des feux de forêt du Canada et des comités consultatifs régionaux. Le Service joue également un rôle actif dans des organismes internationaux de foresterie comme l'Union internationale des organisations de recherche forestière et l'Organisation pour l'alimentation et l'agriculture, de même qu'au sein de délégations de nature technique ou commerciale.

The Canadian Forestry Service Air Pollution Program and Bibliography

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ABSTRACT

This publication outlines the nature of the Canadian Forestry Service (CFS) Air Pollution Program and explains the structure and arrangement of the Annotated Bibliography of publications generated from it. The bibliography comprises abstracts of publications produced between 1972 and 1988.

RÉSUMÉ

Cette publication présente un aperçu du Programme relatif à la pollution atmosphérique du Service canadien des forêts (SCF) en plus d'expliquer la structure et la disposition de la bibliographie annotée des publications qui en découlent. La bibliographie comprend des résumés de publications parues de 1972 à 1988.

THE PROGRAM

The Canadian Forestry Service has over 50 years of experience in the detection and monitoring of air pollution effects around strong point sources of air pollution. During the late 1970s, this activity was enlarged and reoriented to include regional air pollution (the "acid rain" problem). The main pollution threat was perceived as arising from wet acidic deposition, especially sulfate, rather than from high ambient concentrations of air pollutants. As there were no widespread visible effects on forests attributable to regional air pollution, the CFS Air Pollution Program concentrated on hidden and potential effects, especially by means of measuring and monitoring hydrologic and nutrient element budgets at three intensively instrumented forest catchment basins located across eastern Canada.

However, following the observation in the early 1980s of forest dieback in certain maple and birch forests in eastern Canada and the recognition of conifer growth that was inexplicably less than expected in other eastern areas, the CFS Air Pollution Program again evolved to deal more comprehensively with these dieback and growth reduction phenomena.

Overall, the aim of the CFS Air Pollution Program is to provide government with a scientific basis for the development of effective air pollution controls. This is accomplished through a range of "in-house" studies, through special studies contracted with university and other authorities, and on a broader scale through the coordination of research conducted in collaboration with other agencies. There are three main objectives:

1. to determine if air pollution contributes to current forest dieback (maple and birch) and to develop methods of preventing or stopping sugar maple stands from declining;

2. to determine air pollutant levels that must not be exceeded to ensure the continued productivity and well-being of forests (this information is essential for designing abatement strategies); and

3. to monitor continuously the health of representative forest ecosystems across Canada (this serves as an early warning system and a check on the adequacy of the implemented control measures).

A. Decline Research

This has four main components: maple dieback in Quebec, birch dieback in New Brunswick; maple decline in the three eastern provinces--Ontario, Quebec, and New Brunswick; and conifer growth reductions throughout the eastern provinces.

The first deals with the serious dieback in sugar maple stands recorded throughout southern Quebec since 1982 (Reference No. 31). Investigations have greatly expanded since 1985, bringing together expertise in silviculture, air pollution, pathology, and mineral nutrition. Scientists from four universities and two provincial ministries collaborate with those from the CFS Laurentian Forestry Centre in Quebec City.

The second initiative is directed at the early leaf browning and premature leaf drop seen in birch along the New Brunswick and sometimes Nova Scotia coastal regions adjacent to the Bay of Fundy (Reference No. 54). The problem was first seen in 1979 and varies in intensity from year to year. It does not appear to be caused by conventional stresses, and CFS scientists from the Maritimes Forestry Centre in Fredericton are collaborating with those from other agencies to discover the cause of this disorder.

The third component is again maple decline, but on a much wider geographical base, involving the species in three Canadian provinces and seven northeastern states. Some 160 plots have been selected initially to embrace conditions of light and heavy acidic deposition, tapped and untapped stands, and three levels of decline severity. Intensive measurements of a variety of stand and site parameters are being made over the 1988-1990 period in an attempt to discover the cause of decline. The U.S. Department of Agriculture Forest Service and the CFS, along with state and provincial agencies, collaborate under the aegis of a formal Memorandum of Understanding (Reference No. 147).

The fourth area is again semicontinental in scope, but focuses on the annual growth trends of important conifer species. An initial investigation (Reference Nos. 49-51) indicated that annual growth of white and red spruces since 1960 has been less than expected. This decline is not readily explained by pests or climate, but resembles a more marked shortfall occurring in the 1900-1920 period. Further data sets of long-term annual ring widths are being examined at the CFS Petawawa National Forestry Institute to see if signals for pollution or climatic events can be identified (Reference No. 75).

B. Process Research

The earlier CFS process research dealt with high ambient concentrations of sulfur dioxide in mainly Ontario and Alberta and of fluorine compounds in Newfoundland. These permitted an understanding of dose-response relationships, constituting the foundation for the specification of desirable air quality standards.

Regional air pollution, not of well-known composition but with the added potential for synergistic and cumulative effects, poses a much more challenging problem. Tree tissues and physiological growth processes may be adversely affected by direct action, soil fertility may be impaired through indirect impingement, and a tree's resistance to insect or disease attack and to extreme climatic events (drought and frost) may be lowered.

References in the Annotated Bibliography may be found exemplifying the many facets of this complex system. Reference No. 63 is just one example of findings in the hydrologic and nutrient budget area. Reference No. 168 deals with the effects of simulated acid rain (SAR) on tree seedling growth, Reference No. 37 of SAR on plant reproductive processes, and Reference No. 170 of SAR on cuticle integrity; the influence of the acidity and nutrient balance of the growing medium on root mycorrhizae development is described in Reference No. 34 and on rootlet mortality in Reference No. 86.

For effects on soils, Reference No. 216 describes how increased acidification affects nutrient leaching, Reference No. 23 deals with the mobilization of soil aluminum, and Reference No. 24 investigates the relative toxicity of the different ionic forms of soil aluminum. Reference Nos. 113 and 145 report on soil nitrogen and soil sulfur transformations, respectively.

Reference No. 249 reports on a novel study testing the effects of soil acidification and aluminum mobilization on the resistance of balsam fir rootlets to Armillaria infection.

At present, the CFS Air Pollution Program continues to examine the effects of simulated acid rain and of gaseous pollutants, such as ozone, on the many key components and processes of forest ecosystems. All studies aim to contribute information on dose-response relationships, which form the basis for indicating desirable air quality characteristics. These may be in terms of upper ambient concentrations of air pollutants or as maximum deposition rates.

The implications of climatic change, carbon dioxide buildup, and nuclear-related developments are other facets that receive attention (Reference Nos. 20, 88, 75, 176, and 178).

C. Forest Monitoring (ARNEWS)

Because regional air pollutants and natural factors can individually or in combination affect the health and development of forests in a variety of ways, a new Acid Rain - National Early Warning System (ARNEWS) was initiated in 1984 (Reference No. 7). The system's specific objectives are:

1. to assess damage sustained by Canadian forests that cannot be attributed to natural causes or to management practices; and
2. to monitor the characteristics of vegetation and soils on a long-term basis to detect and separate changes caused by air pollutants, natural stresses, and normal growth development in representative forest ecosystems.

A total of 106 plots makes up the network. They are distributed across Canada, with an eastern bias to reflect the pattern of pollution.

D. Watershed Monitoring

In the late 1970s, when the instrumented and multidisciplinary watersheds were set up, the CFS felt that it was first essential to characterize and understand the main hydrologic and nutrient element cycles associated with representative forest sites, if the subtle impacts of acidic deposition were to be detectable. The objectives of the watershed studies were:

1. to provide a baseline of how pollutants and other elements move within a forested ecosystem;
2. to yield a long-term monitoring record of inputs and outputs of pollutants and other elements at three locations in eastern Canada; and
3. to provide well-documented sites at which studies from several agencies could be carried out in cooperation.

ANNOTATED BIBLIOGRAPHY

The Annotated Bibliography lists 252 papers, representing the most important publications issued from 1972 up to the end of 1987, as well as a few that have been accepted for publication in 1988. Included is research that has been conducted "in house" by CFS scientists, as well as that conducted at universities and elsewhere with CFS fiscal support. The purpose is to make available for reference and for further study a single document that embraces the principal findings of a major phase of the CFS Air Pollution Program. Further periodic compilations are planned.

The Annotated Bibliography does not include all earlier CFS publications. Much of the pre-1973 work on strong point-source air pollution may be found in Reference Nos. 73 and 204, and the Annual Reports of the CFS Forest Insect and Disease Survey Organization (e.g., Reference Nos. 54-56) may be consulted for accounts of pollution-related problems. Numerous shorter and semipopular types of presentation are not included.

Basically, the arrangement of publications is alphabetical by senior or sole author, citations being in the conventional style. Following each citation, in parentheses, is a CFS Establishment abbreviation, the full address of which, hence the authors' location, is given on page 6. This is intended to facilitate contact and exchanges.

Every citation is annotated. Annotations are sometimes similar to journal abstracts; for many, however, longer and more informative narratives have been especially written.

Finally, to assist in the further use of the bibliography, three summaries or indexes are included. One, on page 7, groups publications by CFS Establishment. The second, on page 8, groups publications falling within some 10 subject areas: reviews, acid rain, fluorides, carbon dioxide, radionuclides, etc. The third, on pages 9-10, groups publications according to discipline: biogeochemistry, dendrochronology, insects and diseases, plant reproduction, etc.

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CANADIAN FORESTRY SERVICE ESTABLISHMENTS

PFC - Pacific Forestry Centre
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Victoria, British Columbia
V8Z 1M5

NoFC - Northern Forestry Centre
5320 - 122nd Street
Edmonton, Alberta
T6H 3S5

GLFC - Great Lakes Forestry Centre
P.O. Box 490
1210 Queen Street East
Sault Ste. Marie, Ontario
P6A 5M7

LFC - Centre de foresterie des Laurentides
1055 rue du P.E.P.S.
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Ste-Foy, Québec
G1V 4C7

CFS-M - Maritimes Forestry Centre
P.O. Box 4000
College Hill
Fredericton, New Brunswick
E3B 5P7

NeFC - Newfoundland Forestry Centre
Building 304, Pleasantville
St. John's, Newfoundland
A1C 5X8

PNFI - Petawawa National Forestry Institute
Chalk River, Ontario
K0J 1J0

CFS-HQ - Canadian Forestry Service Headquarters
351 St. Joseph Blvd.
Hull, Quebec
K1A 1G5

PUBLICATIONS GROUPED BY CFS ESTABLISHMENT

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ANNOTATED BIBLIOGRAPHY

1. Addison, J.A. 1984. The effects of elemental sulfur on soil- and litter-dwelling arthropods. Univ. Calgary report to Can. For. Serv., Edmonton, Alta. (NoFC)

The potential of different groups of soil- and litter-dwelling arthropods for use as biomonitoring tools in areas contaminated with elemental sulfur dust was examined near a sour gas processing plant at Strachan, Alberta. Collembola densities at sites closest to the S blocks were extremely low (42 to 547 individuals m^{-1}) as compared with densities of 10 400 to 13 600 individuals m^{-1} at more distant sites. In addition, clear responses to the pollution gradient could be seen in collembolan species number and diversity. Mite numbers were significantly reduced only at the closest site, and no relationship could be detected between the number of carabids or spiders captured at the various sites and the pollution gradient. It was concluded that, of all the taxa investigated, Collembola showed the best potential for use in biomonitoring studies of sulfur pollution.

2. Addison, P.A. 1980a. Baseline condition of jack pine biomonitoring plots in the Athabasca Oil Sands area, 1976 and 1977. Alberta Oil Sands Environ. Res. Program Rep. No. 98, Alberta Environ. 38 p. (NoFC)

In 1976-77, a set of 13 jack pine biomonitoring sites was established in the Athabasca Oil Sands area in order to biomonitor both impingement and impact of emissions characteristic of oil sands extraction operations. No measurable air pollution effect was observed on either vascular or lichen communities at any site even though significantly higher tissue pollutant concentrations were documented from sites within 10 km of GCOS. The importance of future time-course sampling of permanent sites is emphasized because our inability to measure a biological effect at these sites may have been purely because of the great natural variability in the region.

3. Addison, P.A. 1980b. Ecological bench-marking and biomonitoring for detection of airborne pollutant effects on vegetation and soils. Alberta Oil Sands Environ. Res. Program Rep. No. 111, Alberta Environ. 43 p. (NoFC)

Biomonitoring plots established in 1976 and 1977 were revisited and quantified with respect to their vascular plant community of the lower stratum, lichen community of black spruce branches, and both soil and plant element contents. There was no measurable change in any of the above factors. Several biomonitoring techniques were tested throughout the 5-year study period of this project. Although there was little measurable effect of air pollution in the area as a whole, certain techniques showed promise for long-term biomonitoring for pollution effects. In general, there was only very limited evidence of biological responses to increased pollutant content in spite of significantly higher pollutant levels in tissues close to the existing industrial developments.

4. Addison, P.A. 1982a. Synergisms of contaminant interaction. Proc. Counc. For. Ind. Workshop on Assimilative Capacity of the Environment, Vancouver, B.C. (NoFC)

A review of the literature on the influence of pollutant mixtures on forest systems was carried out. We know a lot about the influence of mixed gaseous pollutants on the physiology and visible symptom development of crop plants. Much less is known of the interaction of soil and gaseous pollutants or how pollutants change in soils. The information that is available can be utilized effectively, as can the great wealth of information on the response of plants to their environment in order to estimate the ultimate impact of pollutant combinations on an ecosystem. This, however, cannot be accomplished without detailed studies on how forest species compare with crop plants with respect to mixed pollutant effects and without detailed information on the state of the environment and the major factors affecting ecosystem processes in the area of concern. Literature studies will provide much to the understanding of how pollutants both singly and in combination could influence forest systems, but they cannot replace well designed and well carried out multidisciplinary research on the influence of pollutants characteristic of forest industries on the forest ecosystem. Descriptive work so prevalent in the literature is an important first step, but without a substantial effort on how ecosystem processes are affected by pollutants, the objective to determine the assimilative capacity of forest systems for pollutants is not possible.

5. Addison, P.A. 1982b. Biomonitoring in the Athabasca Oil Sands area: progress and pitfalls. Pages 331-367 in Proc. Symp./ Workshop on Acid Forming Emissions in Alberta and their Ecological Effects. Alberta Environ., Can. Pet. Assoc., Oil Sands Environ. Study Group, Edmonton, Alta. 648 p. (NoFC)

A set of 13 jack pine monitoring sites was established in the Athabasca Oil Sands area in 1976. Specific sites were selected based on the air-shed characteristics and topography yet were distributed as evenly as possible throughout the area. These sites were sufficiently scattered to permit long-term biomonitoring of both present and proposed air pollution sources.

Description of each site consisted mainly of quantification of the vascular plant community with respect to both vegetational and soil components. Lichens, because of their high sensitivity to air pollutants, also were described in detail. Low-level aerial photography provided a baseline overview for tree crown impact by air pollutants near oil sands operations.

To date, the approach of the Northern Forest Research Centre has been to work with well-defined, permanently marked and well-documented sites. The advantages of this approach are as follows:

1. It permits simultaneous assessment of numerous factors that may respond to pollutants. This results in greater reliability, because it substantially reduces the possibility of a chance occurrence being interpreted as a meaningful response.

2. It permits the interpretation of one factor through the use of others.

3. It reduces the natural variability that has to be dealt with in all ecosystems by allowing measurements of the same site over time.

4. It permits the establishment of a system that takes into consideration different types and rates of response.

5. It permits comparison of different types of responses and allows testing of the reliability and reproducibility of specific techniques.

This approach, however, is not without disadvantages. Only a small number of sites (<30) can be handled since the technique is labor intensive. Sites must also be representative of the area, and this is particularly difficult to accomplish in heterogeneous areas. A team approach, which is often difficult to maintain, is essential owing to the multidisciplinary nature of the work.

In general, in the Athabasca Oil Sands area of Alberta it was possible to demonstrate that pollutants characteristic of oil sands operations were not evenly distributed. Distinct gradients in lichen, moss and vascular plant elemental content and sulfation rate were observed in the vicinity of Suncor. Demonstration of plant response to the deposited pollutants, on the other hand, was much more difficult. Long-term measures such as vascular plant community change, soil nutrient change, and tree growth could not be related to pollutant deposition. Some plant responses such as lichen community change and thallus condition, jack pine seed germination and needle retention appeared to be influenced by air pollution. Physiological responses of both vascular plants and lichens were far too variable to be useful. Soil chemical measurements, although highly variable, are essential for characterization of the site and may help in monitoring if deposition is great or long-term.

6. Addison, P.A. 1984. Quantification of branch-dwelling lichens for the detection of air pollution impact. Lichenologist 16:297-304. (NoFC)

In the Athabasca Oil Sands area of Alberta, a study was carried out to test a lichen community transplant technique and to determine the influence of oil sands extraction and processing emissions on lichen cover of transplanted communities. Measurement errors of a photographic technique for the determination of lichen cover were dependent upon lichen species but were not correlated to lichen cover. When lichen covers were small, therefore, relative errors were very large. Changes in cover of naturally occurring lichen communities on black spruce branches were not significant over a 4-year period. Lichen communities transplanted under jack pine and white spruce trees had cover changes with time not different from naturally occurring communities even over a period of years. Significant cover reductions of some lichen groups occurred on transplanted branches under white spruce within 8.3 km of a pollution source. Evernia, Cetraria and Bryoria groups were reduced, whereas Hypogymnia showed no response over a 3-year measurement period. Reductions in lichen cover were greater than the demonstrated precision of the technique.

7. Addison, P.A. 1988. Monitoring the health of a forest: a Canadian approach. Proc. 4th World Wilderness Congr. Symp. on Acid Rain, Denver, CO (in press). (CFS-HQ)

In Canada, acid rain is the generic term encompassing all forms of air pollution--wet and dry deposition, gaseous pollutant concentrations, and airborne particulates. It was because these pollutants, alone or in combination, may directly or indirectly affect the health of Canada's forests that, in 1984, the Canadian Forestry Service initiated a national forest monitoring program (Acid Rain - National Early Warning System or AR-NEWS).

Research studies on pollutant effects for the past 15-20 years demonstrated that it is not possible to define specific symptoms of acid rain on native tree species or specific responses of the forest ecosystem. Consequently, AR-NEWS monitored incipient acid rain effects by determining the forest's state of health rather than by concentrating on specific pollutant responses.

The detection system entails experienced forest rangers assessing both specific plots and the forest as a whole for extraordinary forest damage. The techniques used include mensurational and symptomatological measurements as well as evaluation of stands for damage from natural and anthropogenic causes. Critical also to the system was the capability of the Canadian Forestry Service to support the detection system with research staff who could carry out studies to explain any abnormalities in forest condition detected during the annual surveys. The ultimate outcome of the monitoring system if unexplained forest damage was detected is a research project on possible causes.

8. Addison, P.A.; Baker, J. 1979. Interim report on ecological benchmarking and biomonitoring for detection of air-borne pollutant effects on vegetation and soils, 1975 to 1978. Alberta Oil Sands Environ. Res. Program Rep. No. 46, Alberta Environ. 38 p. (NoFC)

A set of 11 sites was established in the Alberta Oil Sands Environmental Research Program study area to provide baseline information on vegetation and soils with respect to air pollution impact. Sites were strategically located for use in long-term biomonitoring and were described with respect to their vascular and cryptogamic species list, stand density and age, soil characteristics and type, and cover and frequency of lower strata species. No apparent impact was detectable that could be attributed to air pollution. Additional sites of a temporary nature were established for use in the development of biomonitoring techniques. Several of these techniques were sensitive enough to detect air pollution impingement in the vicinity of Great Canadian Oil Sands Ltd. operations.

9. Addison, P.A.; Jensen, K.F. 1987. Long-range air pollution effects on the forest ecosystem. Proc. 52nd North Am. Wilderness and Natural Resources Conf., Quebec City, Que. (CFS-HQ)

Air pollution cannot be considered to act independently in the environment any more than any other factor. Insects, disease, fire, climate, water and nutrients may all play an important role in influencing how trees are affected by pollutants. The converse is also true. In the case of dendrochronological studies, many attempts have been made to relate air pollution to tree growth changes. As a result of the complexity and variability in the forest ecosystem and the fact that the histories of both air pollution and natural stresses are rarely known precisely, the correlations resulting from dendrochronological studies cannot be used to meet the "Rules of Proof" that air pollution is a causal factor.

The contribution air pollution is making to the forest declines that we see today is still largely unknown and will remain that way for many years to come. If we wait until irrefutable proof is obtained, we take what I would consider to be the unacceptable risk that large forest areas may be affected. Pollution control is the only ultimate solution to pollution effects. It is critical that the best inferential evidence available be provided to policy makers so that intelligent decisions can be made about whether and what pollutants need to be controlled to ensure the integrity of the forest system for generations to come.

10. Addison, P.A.; Kennedy, K.A.; Maynard, D.G. 1984. Effects of sour gas processing on a forest ecosystem in west-central Alberta. Can. For. Serv. Inf. Rep. NOR-X-265. (NoFC)

The impingement and impact of gaseous and particulate sulfur pollution from two sour gas processing plants on lodgepole pine (Pinus contorta Dougl. var. latifolia Englem.) forests in west-central Alberta were studied. Pollutants in the area were not evenly distributed. Elemental S dust appeared to be limited to an area within 1.5 km of gas plant operations, but elevated sulfur gas concentrations extended 45 km northeast of the major pollutant source. The four sites impinged by elemental S had noticeable differences in several soil chemical properties. Plant response to soil changes was dramatic, although no change in growth or reproduction was observed in lodgepole pine. The normal concentration of sulfur gases did not have any measurable impact on the soils or vascular plants of the region. Lichen cover appeared to respond inconsistently to gaseous emissions.

11. Addison, P.A.; Khan, A.A.; Baker, J.; Malhotra, S.S.; Theriault, F.; Radford, F.; Ridgway, J.I. 1981. Effect of mixed pollutants on soil-plant microcosms. Alberta Oil Sands Environ. Res. Program Rep. No. OF-99, Alberta Environ. (NoFC)

Experiments were initiated to determine the long-term effects of continued deposition of a complex of pollutants on the forest system in the Athabasca Oil Sands area. A plant-soil microcosm (jack pine - Dystric Brunisol) had various pollutant mixtures added to its surface at levels representing up to 104 years of deposition. No measurable plant responses have been detected to date; however, measurements of both plant and soil responses are continuing.

12. Addison, P.A.; Khan, A.A.; L'Hirondelle, S.J.; Theriault, F. 1982. Impact of air pollutants on forest vegetation and soils. Alberta Oil Sands Environ. Res. Program Rep. No. OF-43, Alberta Environ. (NoFC)

No evidence of impact on jack pine physiology was found when concentrations of the dominant pollutants from the Oil Sands operations equivalent to 104 years of soluble deposition were added to intact soil cores. Evidence indicates that the surface litter layer or LFH horizon plays a dominant role in protecting both the mineral soil and established plants from pollutant effects either through an improved nutrient balance or by complexing the pollutants. Several major cations increase in solubility with the addition of SO_4, and nutrient depletion may occur in field situations. Metal pollutants did not enhance the solubility of cations as has been reported elsewhere.

13. Addison, P.A.; L'Hirondelle, S.J.; Maynard, D.G.; Malhotra, S.S.; Khan, A.A. 1985. Effect of oil sands processing emissions on the boreal forest. Can. For. Serv. Inf. Rep. NOR-X-284, Edmonton, Alta. (NoFC)

A review of the cooperative work between Canadian Forestry Service and Alberta Environment was carried out. In addition to a description of the contributions to the literature from 1974 to 1984, the report summarized unpublished and internal Alberta Environment reports in the areas of pollutant (metals, sulfate and nitrate) contamination of soils and resultant biochemical and physiological responses of jack pine growing on them.

14. Addison, P.A.; Linzon, S.N.; Hogan, G.D., editors. 1986. Assessment of the state of knowledge on the long-range transport of air pollutants and acid rain. Part 4. Terrestrial effects. LRTAP Liaison Office, Research Monitoring and Coordinating Committee, Toronto, Ont. 80 p. (CFS-HQ)

The Canadian assessment of the current state of knowledge of LRTAP provides a sound technical and scientific overview that can provide the basis for emission control strategies. In order to achieve this purpose for the terrestrial sector, a single question was posed by the Terrestrial Effects Sub-Group of the Federal/Provincial Research Monitoring and Coordinating Committee that would focus the report and assist policy makers: "What is the evidence for LRTAP effects on the terrestrial ecosystem?"

The answer to this question is based on the literature and current activities of scientists as a whole, including, but not limited by, the results presented at the International Symposium on Acid Precipitation held at Muskoka in 1985.

Contributions to the assessment have been made by P.A. Addison, P.J. Rennie (CFS-HQ), R.M. Cox, M.K. Mahendrappa (CFS-M), R. Boutin, G. Robitaille (LFC), N.W. Foster, G.D. Hogan, I.K. Morrison (GLFC), A.J.S. Tims (New Brunswick Ministry of Municipal Affairs and Environment), M.L. Carrier (Quebec Ministry of Energy and Resources), D. Dimma, A. Kuja, S.N. Linzon, R.G. Pearson (Ontario Ministry of Environment), D. Wotton (Manitoba

Environment), and K. Fischer (Canadian Wildlife Service).

15. Addison, P.A.; Malhotra, S.S. 1979. Symptomatology and threshold levels of air pollutant injury to vegetation 1978. Alberta Oil Sands Environ. Res. Program Rep. No. OF-1, Alberta Environ. (NoFC)

The dominant woody boreal forest plant species were fumigated with 0.34 ppm SO_2 under controlled conditions in the laboratory in order to rank their physiological and visual sensitivities to the air pollutant. Deciduous trees and shrubs were much more sensitive than conifers, presumably because SO_2 can enter broad leaves much more easily than needles. Labrador tea was intermediate in sensitivity to SO_2 and so were its leaf resistances to pollutant uptake. Jack pine was more sensitive than either black or white spruce, whereas it was not possible to rank the broad-leaved deciduous species.

16. Addison, P.A.; Malhotra, S.S.; Khan, A.A. 1984. Effect of sulfur dioxide on woody boreal forest species grown on native soils and tailings. J. Environ. Qual. 13:333-336. (NoFC)

The study was carried out on the influence of 0.34 μL^{-1} (Canadian maximum acceptable limit) of SO_2 on net CO_2 assimilation rate (NAR) and visible symptom development of several boreal forest woody species. Fumigation with SO_2 significantly reduced NAR in all species and produced visible symptoms of injury in 2 to 20 d. The decrease in NAR of deciduous species (aspen Populus tremuloides Michx.), willow (Salix sp.), green alder (Alnus crispa (Ait.) Pursh), and paper birch (Betula papyrifera Marsh.)) was significantly more rapid than that of conifers (jack pine (Pinus banksiana Lamb.), white spruce (Picea glauca (Moench) Voss), and black spruce (P. mariana (Mill.) BSP)) or an evergreen angiosperm (labrador tea (Ledum groenlandicum Oeder)) when grown on a fertilized Brunisol. Visible symptoms also appeared earlier in deciduous species but in all cases did not appear until NAR had decreased considerably. These metabolic and visible responses appeared to be related to differences in sulfur uptake owing in part to higher gas exchange rates for deciduous species than for conifers.

Conifers growing in oil sands tailings responded to SO_2 with a significantly more rapid decrease in NAR as compared with those growing in the Brunisol. Because both soils were fertilized, nutrient deficiencies were ruled out as a cause. It is suggested that the conifers obtained from the tailings dike were predisposed to SO_2 fumigation by either the presence of toxic material in the tailings or their history of exposure to moderate levels of SO_2 or to moisture stress. Sulfur uptake and visible symptom development were not different on tailings as compared with the Brunisol.

17. Addison, P.A.; Puckett, K.J. 1980. Deposition of atmospheric pollutants as measured by lichen element content in the Athabasca Oil Sands area. Can. J. Bot. 58:2323-2334. (NoFC)

The aluminum, potassium, sulfur, titanium and vanadium contents of the lichens Cladina arbuscula (Wallr.) Hale and W. Culb., Evernia mesomorpha Nyl. and Hypogymnia physodes (L.) Nyl. were determined for up to 69 sites in the Athabasca Oil Sands area in northern Alberta. The elemental accumulation by these lichens was related to both gaseous and particulate emissions from industrial sources and to a localized windblown dust component. The deposition of atmospheric emissions around an oil-extraction plant as measured by lichen thallus concentration closely followed the distribution patterns measured by physical and chemical methods. Visible changes in the thallus condition appeared to be related to the element concentrations.

18. Addison, P.A.; Rennie, P.J. 1987. Long-range transport of air pollution. Can. For. Serv., Res. Tech. Serv. Advis. Rep., Ottawa, Ont. 30 p. (CFS-HQ)

The state of knowledge on forest decline and growth reductions as they relate to air pollution is presented along with a description of the Canadian Forestry Service LRTAP Program.

19. Altshuller, A.P.; McBean, G.A. 1979. The LRTAP problem in North America: a preliminary overview. Prepared by the United States-Canada Research Consultation Group (RCG) on the Long-Range Transport of Air Pollutants. (CFS-HQ)

An authoritative synopsis of current knowledge in the acid rain and air pollution area dealing with emissions, transboundary fluxes, atmospheric modelling and deposition, and the effects on aquatic and terrestrial ecosystems. Numerous authorities from the RCG contributed, and further literature is cited.

20. Apps, M.J.; Duke, M.J.M.; Turner, B.V. 1985. Fission track mapping of uranium in black spruce (Picea mariana (Mill.) B.S.P.) twigs. J. Radioanal. Nucl. Chem. 110(1):243-252. (NoFC)

Examination of fission track maps of black spruce twigs from areas of uranium mineralization and mill tailings shows uranium to be mostly concentrated and uniform in the bark rhytidome, with less than 5% in the woody xylem material.

Arguments are put forward in support of vascular transport, although clear distinction between foliar and root absorption cannot be made. The observation of decreasing uranium content with the increasing age of black spruce twigs by an earlier worker can now be explained by the reduced fraction occupied by uranium enriched bark relative to the total twig biomass with age.

21. Apps, M.J.; Duke, M.J.M.; Stephens-Newsham, L.G. 1988. A study of radionuclides in vegetation on abandoned uranium tailings. J. Radioanal. Nucl. Chem. (in press). (NoFC)

A study has been carried out of the uptake of uranium and other radionuclides by plants growing on abandoned tailings from a uranium mining operation. Assay methods included instrumental neutron activation analysis, delayed neutron counting, fission track imaging and counting of natural radioactivity. Care was taken to avoid contamination of the plant material, and a number of methods are described to identify such contamination. All plants observed showed high uptake of radionuclides, compared to plants studied from naturally uraniferous and control areas. Graminoid (grass-like) plants showed significant uptake in the above-ground parts while woody plants showed exceedingly high uranium accumulation in the root portions. These results have significance in determination of the spread of radioactive material from such sites.

22. Arp, P.A.; Manasc, J. 1988. Red spruce stands downwind from a coal-burning power generator: tree-ring analysis. Can. J. For. Res. 18:251-264. (CFS-M)

Tree-rings of red spruce (Picea rubens Sarg.) in uneven-aged forest stands downwind of an SO_2-source (a coal-burning power generator) were analyzed in terms of spatial and temporal trends for bole increments and elemental concentrations (Al, Ca, Mg, K, P, Mn, Zn, Fe, Ni, Cu, Cr) in xylem. Five-year core segments were pooled with respect to distance from emission source, time of wood formation, and tree age (young trees < 35 years; old trees > 45 years). Soil analysis was done for all stands (total of 28) by soil layer (forest floor, A and B horizons) for pH, exchangeable K, Ca, Mg, Al, and oxalate-extractable Al and Fe. Also analyzed was the snowpack at each stand at three sampling dates in February and March 1986.

The snow data for pH, Ca, Mg, K, and SO_4 were highly variable, with some of the variability presumably related to fall-out of fly ash. The soil data were also variable, but revealed a gain of water-soluble and bicarbonate-extractable SO_4, and a loss of exchangeable Mg with increasing proximity to the power generator. Magnesium levels in the wood of the red spruce trees showed a similar trend.

Wood concentrations for Ca, Mg, Mn, and Zn were found to decrease with increasing stand age. In contrast, wood concentrations for P, K, Fe, Ni, Cu and Cr were highest in the most recently formed xylem. Some of these variations were probably affected (i) by the affinity of the wood for each element during wood formation, or (ii) by removal through flow of xylem sap. Some of these trends may also reflect changed ion availabilities in the soil, or may be due to air pollution.

Trends for the age-related variations of mean bole increments in each of the uneven-aged stands were probably affected by within-stand competition modified by selective logging, and by recurring outbreaks of spruce budworm (Choristoneura fumiferana Clem.). An enhanced rate of SO_2 emission since about 1965 may also have had a negative effect on radial bole growth.

The availability of soil water appeared to be a principal factor in relating a tree growth index to year by year climate variations. This tree growth index (developed for an even-aged stand of red spruce upwind from the power generator) was positively related to precipitation of the preceding year, and to precipitation in July and August (time of late-wood formation). The growth index was negatively related to prolonged periods of high temperatures during earlywood formation.

23. Arp, P.A.; Ouimet, R. 1986a. Aluminum speciation in soil solutions: equilibrium calculations. Water Air Soil Pollut. 31:359-366. (CFS-M)

A computer simulation was done to illustrate how the equilibrium solubility and speciation of Al in well-aerated soil solutions may be affected by pH (from 2.0 to 10.0), organic acids (citric, oxalic, phthalic, and salicylic acid), metal ions (K, Mg, Ca, Al, Fe), inorganic ligands (F, OH, SO_4, PO_4, CO_3, and SiO_3), and type of Al-containing solid (kaolinite, gibbsite, or amorphous $Al(OH)_3$) thought to be present. The simulation indicated that the type of Al-oxide/hydroxide considered has a substantial influence on the inorganic and organic equilibrium composition of the soil solution, and on the occurrence (or non-occurrence) of other Al-minerals such as $KAl_3(SO_4)_2(OH)_6$ (alunite) and $Al(SO_4)(OH).5H_2O$ (jurbanite).

24. Arp, P.A.; Ouimet, R. 1986b. Uptake of Al, Ca, and P in black spruce seedlings: effect of organic versus inorganic Al in nutrient solutions. Water Air Soil Pollut. 31:367-375. (CFS-M)

Two-year-old black spruce seedlings (Picea mariana (Mill.) B.S.P.) of greenhouse-grown paper-pot stock were subjected to chemically well-characterized nutrient solutions for 28 days to assess the elemental uptake (Al, P, Ca) of these plants in response to organic versus inorganic Al in the rooting medium ($pH=3.0$; $0 < \text{total Al} < 48 \text{ mg L}^{-1}$). Oxalate additions to the nutrient solutions ($0 < Ox < 2.4$ mmol) served as organic Al-complexing agent. The results indicated that the plants took up Al in proportion to the Al concentration of the rooting medium, with Al uptake from the Al-Ox treatments somewhat more extensive than the Al uptake from the inorganic Al treatments. Furthermore, root Al >> shoot Al for both cases. The pattern of P uptake was similar to that of Al uptake but for the roots only, i.e. root P was proportional to root Al. Increased root P was not associated with increased shoot P. Calcium content of the roots was slightly reduced with increased inorganic and organic Al, but increased strongly with increasing oxalate in the rooting medium.

25. Auclair, A.N.D. 1987a. The distribution of forest declines in Eastern Canada. Pages 307-319 in L. Kairiukstis, S. Nilsson, and A. Straszak, eds. Proc. Workshop on Forest Decline and Reproduction: Regional and Global Consequences, 23-28 March, Int. Inst. Appl. Syst. Anal., Pol. Acad. Sci., Int. Union For. Res. Org., Krakow, Poland. (CFS-HQ)

This paper presents a very preliminary account of forest decline over eastern Canada. Canadian concern over the role of "acid rain" in the recent surge of forest decline has prompted research on the effects of air pollution on tree health and tree growth. This paper will not discuss this research. Rather it will emphasize the geographic incidence of forest declines that may provide a valuable basis for further studies on environmental correlation and etiology.

In contrast to impressions that forest declines are well-documented in eastern North America, it has proven difficult to assemble complete information on the nature and extent of tree declines over species ranges in eastern Canada (and the United States). Maps and a description of symptoms are available in some provinces and some states on some species but a coherent overall picture is lacking. Several projects currently in progress are attempting to achieve this.

26. Auclair, A.N.D. 1987b. The climate change theory of forest decline. In D.P. Lavender, ed. Proc. IUFRO Conf. on Woody Plant Growth in a Changing Physical and Chemical Environment, Univ. British Columbia, Vancouver, B.C. (CFS-HQ)

A marked relation was evident between climate warming in the northern hemisphere and forest decline. The onset of widespread crown dieback in 1925, 1937 and 1981 on tree species of Northern Hardwoods in eastern Canada was related closely to episodes of rapid increase in global temperature. A theory was proposed based on literature evidence linking extreme climatic variations with tree root mortality. Detailed analysis of the erratic 1981 winter and spring in southern Quebec indicated dieback on sugar maple resulted from winter frost damage combined with desiccation at a time of persistent soil ice in late spring. Rather than a single general decline, dieback on sugar maple was seen to be an aggregate of several localized declines resulting from different and sometimes compounding extreme variations in weather. These observations implicated strongly the "greenhouse gases" as well as "acid rain" in the debate on the inciting cause of forest decline and suggested new effective directions for research

27. Baker, J. 1977. Nutrient levels in rainfall, lodgepole pine foliage, and soils surrounding two sulfur gas extraction plants in Strachan, Alberta. Can. For. Serv. Inf. Rep. NOR-X-194. (NoFC)

Analyses of rainfall, lodgepole pine tissues and soils were carried out on samples from control and SO_2-impinged areas around two gas processing plants. Samples of rainfall from the more heavily exposed site contained greater amounts of SO_4-S than those from the control. Lodgepole pine needle and twig tissues contained varying amounts of cations and anions depending on the source of the material. Tissues from the sulfur-exposed sites contained greater amounts of sulfur and aluminum but less calcium, magnesium and phosphorus than control tissues. Ionic composition of soil solutions and exchange complexes from the two general sample areas also differed. Samples from the more heavily impinged areas showed lesser amounts of basic ions (Ca, Mg, K, etc.) and larger amounts of acidic constituents (Al, S, etc.) even though the same general soil type prevailed over the entire study area.

28. Baker, J. 1980. Differences in the composition of soils under open and canopy conditions at two sites close-in to the Great Canadian Oil Sands Operation, Fort McMurray, Alberta. Alberta Oil Sands Environ. Res. Program Rep. No. 97, Alberta Environ. 20 p. (NoFC)

Soils sampled at sites 1 and 2 (2.3 and 5.3 km south of the Great Canadian Oil Sands plant, Fort McMurray) were found to differ statistically with reference to several macro-nutrients. Soils under cover of a canopy and those in open areas differed considerably with respect to soil nutrients and pH. Differences in nutrient concentrations under open versus covered soils probably are due mainly to effects of the canopy; however, this may not fully explain soil sulfur and titanium concentrations. Jack pine foliage sampled at site 12 was more concentrated in S than that of samples at site 2, suggesting the possibility that atmospheric sulfur may have played a role. Other foliar nutrient differences more likely are the result of other natural phenomena. To date, despite the higher S concentration in both jack pine foliage and soils under the canopy at site 1, there is no conclusive evidence that atmospheric pollutants emitted as a result of the overall exploration operation have as yet altered the existing soil nutrient regime of the study area, or are responsible for differences observed between the two sites.

29. Baker, J.; Hocking, D.; Nyborg, M. 1977. Acidity of open and intercepted precipitation in forests and effects on forest soils in Alberta, Canada. Water Air Soil Pollut. 7:449-460. (NoFC)

Emissions of SO_2 appear to have an acidifying effect on grossfall (open rainfall), throughfall, stemflow and soil solution at sites near major sources. Resulting effects on soil chemistry include elevated extractable acidity and aluminum and depressed exchangeable bases, especially Ca and Mg. These changes are mostly in the incipient phases in the study area.

30. Blauel, R.A.; Hocking, D. 1974. Air pollution and forest decline near a nickel smelter. Can. For. Serv. Inf. Rep. NOR-X-115. (NoFC)

Large quantities of sulfur dioxide and particulate matter are being released from a high stack near Thompson as a means of smelter waste disposal. Atmospheric dispersal of these pollutants has resulted in over 50 square miles of patchy forest decline. All components of the forest vegetation exhibit effects of direct pollutant deposition. Impacts range from patches of tree decline and mortality through to general depletion of sensitive cryptogams. This decline will intensify and the area of decline will expand under current pollutant emission rates. Contamination of soil organic matter has been detected over a much greater area. Levels of sulfur and nickel are highly elevated near the smokestack and decrease with distance from it. Nickel and possibly other heavy metals are building up to toxic levels which will be impossible to correct economically. This represents a high potential for severe site degradation as a further outcome to aerial dispersal and dilution of the smelted wastes.

31. Bordeleau, C.; Guérin, D.; Innes, L.; Lachance, D.; Picher, R. 1987. Dieback in maple stands, in Quebec 1987. Insects and Diseases of Trees, Supplement to Forest Conservation, 54(10). (LFC)

Dieback is seen as the major pathological problem in the hardwood forests of Quebec. Aerial survey maps and data are shown for areas north of the Ottawa river flown in 1987. Of 964 327 ha surveyed, 48.7% is healthy or little affected, 50.4% lightly so, and 0.9% moderately to heavily affected. Temporal comparisons made between 1983 and 1986 on study plots in other areas show an increase in both extent and degree of dieback. A short account is included of the 25 permanent sample plots established in 1984 and 1985 throughout Quebec as part of the Acid Rain National Early Warning System.

32. Boutin, R.; Robitaille, G. 1987. Effects of endogenous and exogenous sources of acidification on the chemical properties of a podzol. Pages 429-436 in R. Perry, R.M. Harrison, J.N.B. Bell, and J.N. Lester, eds. Acid rain: Scientific and technical advances. Publ. Div., Selper Ltd., London. (LFC)

An in vitro acidification experiment was performed on reconstituted profiles of an orthic ferro-humic podzol. Endogenous production of protons associated with nitrification was responsible for a significant drop of pH and exchangeable bases in the organic horizons LF and H. This process was more effective in leaching K than Mg and Ca as a percentage of the initial level. The converse was true for acidification by exogenous sources; compared to the control (pH 5.6), acidified water (pH 4.3 to pH 2.6 with a 2/1 equivalent ratio of H_2SO_4/HNO_3) induced a significant gradient of Ca and Mg losses while K losses were significant only at pH 2.6. In the mineral horizons, bases were not substantially depleted, and the acid treatments induced a significant drop of pH related to an increased concentration of Al in soil solution.

33. Brand, D.G.; Kehoe, P.; Connors, M. 1986. Coniferous afforestation leads to soil acidification in central Ontario. Can. J. For. Res. 16:1389-1391. (PNFI)

The soil pH under 20 coniferous plantations on abandoned farmland at the Petawawa National Forestry Institute was remeasured after 46 years and showed a significant decrease. Soils under white spruce (Picea glauca (Moench) Voss) showed the greatest degree of acidification, with the average pH in 13 plantations decreasing by 1.28.

34. Camire, C.; Gingras, J.F. 1982. Potential effects of acid rain on germination, growth, and mycorrhizal development in balsam fir (Abies balsamea (L.) Mill.) seedlings. (Available only in French.) Contract report to LFC/CFS. 29 p. (LFC)

The potential effects of acid rain on germination, in vitro growth, and in situ mycorrhizal infection were studied, as was the effect of acidity on the microbiological activity of the humus. Levels of pH from 2.0 to 5.6 did not significantly affect the germinability of firs. In vitro growth of firs grown on the LF horizon was reduced by treatments of 10 meq $H-H_2SO_4$/100 g and over. In the field, mycorrhizal infection in 1- to 6-year-old seedlings was decreased only at the highest rate of 100 meq H/100 g LF. The application of acid inhibited microbiological activity of the LF horizon, even at low levels.

35. Camire, C.; Lesage, D. 1982. Potential effects of acid rain on a podzol. (Available only in French.) Contract report to LFC/CFS. 30 p.; 141 figs. (LFC)

The potential effects of acid rain were investigated through in vitro incubation of a podzol from Laurentide Park, Quebec, treated with different concentrations of sulfuric acid. To organic horizons, 0-100 meq H 100 g^{-1} was added; to the mineral horizons, the range added was 0-20 meq H 100 g^{-1}. The LF horizon exhibited strong buffer capacity. Increased concentration of applied sulfuric acid was correlated, in this same horizon, with increased net mineralization of nitrogen but decreased nitrification. In addition, the net mineralization of sulfur seemed little affected by up to 5 meq H 100 g^{-1} of applied sulfuric acid. The spodic horizons strongly fixed the applied sulfates. In all horizons but the spodic, phosphorus was solubilized by the increased acidity. Calcium was the base most strongly solubilized by treatment, and the minerals were weathered. Aluminum was highly solubilized in low concentrations of applied acid.

36. Camire, C.; Pregent, G. 1987. Acidification, ion leaching, and sulfate adsorption in a Ferro-Humic Podzol subjected to additions of acidity. (Available only in French.) Contract report to LFC/CFS. 47 p.; figs.; tables. (LFC)

The soil solution at the interface of the H and Ae horizons of a Ferro-Humic Podzol treated with acid (H_2SO_4-HNO_3) was sampled during two seasons (summers of 1984 and 1985) using tension lysimeters and analyzed in the laboratory. Samples of the various horizons of the profile were also taken for laboratory analysis 2 weeks after the treatments were completed in the fall of 1985. The F horizon of the Podzol exhibited a strong buffer capacity; only the most acidic treatment, leaching of bases (Ca, Mg, K and Na), was significant for the F and H horizons, whereas there was an accumulation of these bases in the Bhf_1 horizon. A large quantity of sulfate (210 mg S-SO_4^{2-} kg^{-1}) was fixed in this horizon (compared with 23 mg S-SO_4^{2-} kg^{-1} for the controls). Sulfate fixation in the Bhf_1 and Bhf_2 horizons is related to the various forms of aluminum. The modified Freundlich equation accurately describes the adsorption by these horizons for equilibrium concentrations up to 90 mM ($\frac{1}{2}SO_4^{2-}$).

37. Cox, R.M. 1983a. Sensitivity of forest plant reproduction to long range transported air pollutants: in vitro sensitivity of pollen to simulated acid rain. New Phytol. 95:269-276. (CFS-M)

Although some studies have been made of the direct effects of wet deposition of acid on plants, few have examined its effects on plant reproductive processes. Reported here are the relative sensitivities of pollen germination and pollen tube growth from 13 forest species to a range of acidities found in ambient rainfall. In vitro assays indicate that pollen of all species tested was significantly influenced by pHs from 5.6 to 2.6. Two-thirds of the species tested had pollen that was significantly inhibited in germination by pH 3.0 (1000 μEq H^+

L^{-1}) whereas few effects were observed at pH 4.6 (25 μEq H^+ L^{-1}). Broad-leaved tree pollens were more sensitive to pH than those of conifers, and those of the understorey and ground flora species tested were of intermediate sensitivity. It is of concern that all values of LD_{50} for pollen germination response to initial culture pH were within the range of acid rain events in eastern Canada. Further research is required into the *in vivo* responses, to determine if reproduction in plants with sensitive pollen is inhibited by ambient levels of acid deposition.

38. Cox, R.M. 1983b. Determination of the sensitivity of pollination processes of different forest flora species to simulated acid rain. Can. For. Serv. contract report. 110 p. (CFS-M)

This report describes studies into the effects of acidity and metals on reproduction in woody and herbaceous plants. The work was carried out at the University of Toronto and most of the results have been published in journal articles by Cox.

39. Cox, R.M. 1983c. The sensitivity of forest flora reproduction to long range transported air pollutants. Pages 823-826 *in* Proc. Int. Conf. Heavy Metals in the Environment. Vol. 2. CEP Consultants Ltd., 26 Albany St., Edinburgh, UK. (CFS-M)

In vitro sensitivities to a range of acidities of 12 tree pollens will be compared and related to those ambient rainfall concentrations in northeastern North America and to canopy strata the species occupy. The effects of field simulations of acid precipitation on *Oenothera parviflora* were examined: LD_{50} dosages for failure of pollen to 1) germinate and 2) produce tubes long enough to penetrate the stigmatic tissue were pH 3.45 and 4.66 respectively. Pollens sampled from *Pinus strobus* from acid and calcareous areas were assayed in the presence of various pH's and Al concentrations. Synergistic interaction will be discussed in relation to Al toxicity, and *in vitro* sensitivity will be related to ecology of the sporophyte and to possible consequences of microgametophyte selection on fitness of future generations.

40. Cox, R.M. 1984. Sensitivity of forest plant reproduction to long range transported air pollutants: *in vitro* and *in vivo* sensitivity of *Oenothera parviflora* L. pollen to simulated acid rain. New Phytol. 97:63-70. (CFS-M)

Effects of simulated acid precipitation on pollination in *Oenothera parviflora* L. from different populations were examined both *in vitro* and *in vivo*. The responses of pollen to acidity (pH 5.6 to 2.6) in standing drop cultures and the stigma receptivity of flowers under field simulations of acid rain were observed. The response of pollen *in vitro* indicated significant inhibitory effects of pH, and demonstrated that pH values <3.6 were inhibitory to both germination and tube growth, when compared with the treatment of pH 5.6. Dosages of LD_{50} for in vitro pollen germination, taken as the initial pH of cultures for the different pollens, ranged from pH 3.49 to 3.72. Stigma receptivity assessed by germination and initial tube growth on the stigmatic surface also declined significantly ($P<0.01$) in response to acid rain simulation prior to hand pollinations. Again simulants <pH 3.6 significantly reduced stigma receptivity compared with the treatment at pH 5.6. Here LD_{50} dosages, taken as the pH of the simulant, were pH 3.45 and 4.66 for the failure of potentially viable pollen to germinate, or produce tubes three times the length of the grain, respectively. These results are discussed in relation to rain chemistry in Southern Ontario, Canada.

41. Cox, R.M. 1985a. Contamination and effects of cadmium in native plants. Pages 101-109 in H. Mislin and O. Rovera, eds. Cadmium--A complex environmental problem. Birkhauser Verlag, Basel, Switzerland. (CFS-M)

This is a review of the effects of cadmium on native plants covering background levels, bioaccumulation and biomonitoring, physiology and toxicology, reproductive processes, and tolerance.

42. Cox, R.M. 1985b. The response of plant reproductive processes to air pollution. Pages 155-170 in T.C. Hutchinson, ed. Proc. NATO Adv. Res. Workshop on Effects of Acidic Deposition and Air Pollutants on Forest, Wetlands and Agricultural Ecosystems, Toronto, Ont. Springer-Verlag, New York, NY. (CFS-M)

The effects on reproductive processes in plants of air pollutants transported over long distances are reviewed and their relevance discussed. In vitro and in vivo experiments to investigate the effects of acidic and trace element components of polluted rain on pollen germination and tube growth are described. The sensitivity to pH of pollen in vitro was related to the species' position in the canopy, whether it was a conifer or deciduous and to the habitat in which the species normally occurred, i.e., boreal forest or calcareous woodland. Most pollen assayed revealed significant inhibitions of germination and germ tube growth in response to pH's currently recorded for daily rain samples collected in eastern Canada. The in vitro effects of trace elements in combination with pH on pollen function are discussed in relation to cation stimulation and synergistic interactions. In vivo inhibition of pollen of evening primrose, Oenothera parviflora, by simulated acid rain is compared with similar inhibition reported in response to SO_2 fumigations which have reduced seed set in some species. Given a degree of overlap in gene expression of tolerance in pollen and the plant from which it came, some implications of pollen mortality brought by air pollution during pollination are discussed.

43. Cox, R.M. 1985c. In vitro and in vivo effects of acidity and trace elements on pollen function. Pages 93-100 in D.L. Mulcahy, G.B. Mulcahy, and E. Ottariano, eds. Biotechnology and biology of pollen. Springer-Verlag, New York, NY. (CFS-M)

Pollen development and activity are known to be among the more sensitive botanical indicators of atmospheric pollution. The pollen of twelve different species occupying various habitats in eastern Canada were sampled and assayed for response to pH in 50 µL standing drop cultures. The thresholds of response of all the pollens tested were within the range of pH experienced in ambient precipitation in eastern Canada. The broad-leaved species receiving direct precipitation were found to be the most pH sensitive. The next most sensitive pollen was sampled from the forest understorey and ground flora species while the least sensitive pollen was sampled from the conifers, which as a group had significantly lower LD_{50} values than the broad-leaved species. Interactions between Cu and pH on pollen germination were investigated by determining the LD_{50} pH dosages. Changes in pollen dose response indicate that some species' sensitivity to pH is influenced by the presence of copper at concentrations currently occurring on occasion in ambient precipitation. Simulations of precipitation events of depth 0.26 cm at various acidities on stigmatic receptivity of Oenothera parviflora indicated acid rain simulants caused a significant reduction in stigma receptivity. Selection of pollen genotypes on the stigmatic surface by the direct effect of air pollution would affect the frequency of pollen genotypes contributing to the next generation.

44. Cox, R.M. 1987a. The effects of wet deposited acidity and copper on the reproductive biology of Populus tremuloides. Pages 141-150 in L. Kairiukstis, S. Nilsson, and A. Straszak, eds. Proc. Workshop on Forest Decline and Reproduction: Regional and Global Consequences, 23-28 March, Int. Inst. Appl. Syst. Anal., Pol. Acad. Sci., Int. Union For. Res. Org., Krakow, Poland. (CFS-M)

Air pollution may impact the sensitive reproductive processes of plants at the time of pollination. Most pollen grains have been shown to be inhibited by ambient levels of acidity now occurring in wet deposition. This paper will use Populus tremuloides as an example to demonstrate how combinations of pollutants in wet deposition may act synergistically on pollen function both in vitro and on the stigmatic surface. Furthermore, the effect of reduced stigmatic receptivity caused by the various simulated acid precipitation treatments at the time of pollination will be related to fruit abortion rates and levels of seed set in this species.

The implication to the plant breeding system of the direct effects of air pollution on pollen function and viability at the time of pollination will be discussed in terms of possible effects on progeny fitness.

45. Cox, R.M. 1987b. Natural variation in sensitivity of reproductive processes in some boreal forest trees to acidity. In Proc. Genetic Effects of Air Pollution in Forest Populations. IUFRO Joint Meeting at Federal Research Centre for Forestry and Forest Products and Institute of Forest Genetics and Forest Tree Breeding, Grosshandorf, West Germany. (CFS-M)

Atmospheric pollution may directly affect plant reproduction at the time of pollination because pollen germination and subsequent tube growth are known to be among the most sensitive pollution indicators. Intraspecific variation in pollen sensitivity to pH was examined in two hardwoods, yellow birch (Betula alleghaniensis Britton), and paper birch (B. papyrifera Marsh.), and two softwoods, white pine (Pinus strobus L.), and red pine (Pinus resinosa Ait.). Attempts were also made to examine the stigmatic environment of the pollination droplet in white pine and relate its acidity to soil pH and to responses of pollen sampled from the same trees. White birch pollens were shown to be as sensitive to acidity as those of yellow birch and in some provenances more sensitive, with LD_{50} dosages of pH equal to 3.9. Variability among provenances was also larger than in yellow birch; however, no significant differences at the 0.05 probability level were found. The significantly increased sensitivity of the two adjacent calcareous and acid soil populations from the Manitoulin area, Ontario, compared with the two New Brunswick populations indicates differences between provenances in pollen LD_{50} dosages. The apparent advantage in terms of germination of the pollen from the acid soil sites at low pH (3.6) and what seems an advantage of the pollen from the calcareous sites at higher pH (>4.0) provide the bases for gamete selection. Significant differences in acidity of the pollination droplet exudate which correlate with site soil acidity provide a mechanism for gametic selection which would have consequences for the breeding system of this species.

46. Cox, R.M. 1987c. Sensitivity of forest plant reproduction to long range transported air pollutants: in vitro sensitivity of pollen to combinations of acidity and trace metals. In Proc. NATO Adv. Res. Workshop on Effects of Acidic Deposition and Air Pollutants on Forest, Wetlands and Agricultural Ecosystems, Toronto, Ont., May 1985. (CFS-M)

The effects of acidic and trace element components of polluted rain on pollen germination and tube growth in vitro are described. The sensitivity of pollen to pH in vitro was related to the species' position in the canopy and was different for conifers and broad-leaved trees. Most pollen assayed revealed significant inhibition of germination and germ tube growth in response to pHs of current rain samples in eastern Canada. Acer saccharum Marsh. and Betula alleghaniensis Britt. pollen in vitro showed a high sensitivity to pH in combination with copper. The pollen of Populus tremuloides L. was shown to be highly sensitive to pH. A synergism between pH and copper on pollen function in this species was also demonstrated. This was in contrast to the general antagonistic interaction of pH and copper noted in the other species tested in which copper by itself was either ineffectual or stimulatory to pollen function. Zinc had little or no effect, whereas lead at the concentrations used significantly inhibited germination of Pinus strobus L. pollen at pH 5.6-3.6 and maximum tube growth of both P. strobus and Pinus resinosa Ait. The increase in pollen mortality in response to air pollution at the time of pollination raises certain implications for reproduction and breeding system function. These implications are also discussed in light of the significant genetic overlap between pollen and sporophytes of higher plants.

47. Cox, R.M. 1987d. Sensitivity of forest plant reproduction to long range transported air pollutants: the effects of wet deposited acidity and copper on reproduction of Populus tremuloides. Poster at Workshop on Forest Decline and Reproduction: Regional and Global Consequences, 23-28 March, Int. Inst. Appl. Syst. Anal., Pol. Acad. Sci., Int. Union For. Res. Org., Krakow, Poland. (CFS-M)

Few, if any, studies have been carried out that examine and relate in vivo pollen germination following simulated wet deposition of acidity and copper with various fruit and seed set parameters of trees. Reported here are the methods used with inflorescences of a wind-pollinated tree, Populus tremuloides. The responses of components of the reproductive system to rain simulants indicated significant ($P < 0.05$) overall response of in vivo pollen germination to pH. The combined germination data demonstrated a significant ($P < 0.05$) negative correlation with pH. However, the response in the absence of copper showed no linear correlation due to a recovery at the lowest pH used (2.6). The effect of rain at the time of pollination was shown to significantly increase fruit abortion. In addition, an overall significant negative correlation was found between fruit abortion and pH. However, in the absence of copper, fruit abortion likewise recovered at the lowest pH (2.6). Seeds per fruit and percentage of placenta with full seeds were significantly reduced at pH 2.6 in the presence of 0.05 mg Cu L^{-1} as compared with the control. These two seed set parameters were also significantly intercorrelated ($P < 0.01$) with fruit abortion, suggesting that lack of seed set may be the cause of the abortion. The significant correlation of both in vivo pollen germination and fruit abortion with pH, especially in the presence of copper, supports the view that inhibition of the pollen on the stigma by the simulated rain is responsible for the lack of seed set above the required threshold that prevents fruit abortion.

48. Cox, R.M. 1988. Sensitivity of forest plant reproduction to acid rain. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (CFS-M)

The relevance and effect of long range transported air pollutants to reproductive processes of forest and native flora will be reviewed and discussed. Included are some effects of ozone and sulphur dioxide where they relate to acidic deposition or to combined effects with acidic deposition. In vitro and in vivo experiments that investigate the effects on pollen of acidic and trace element components of polluted rain will be described. The in vitro pollen sensitivity to pH was related to canopy strata and plant taxon together with, in one instance, the soil type of the population from which it was collected. Most pollen assayed revealed that their threshold of response to pH is exceeded by the pH recorded for daily rain samples collected at one rural site in Southern Ontario. The in vitro effects on pollen of cadmium and aluminum in combination with pH will be discussed in relation to cation stimulation of pollen and to synergistic interaction with pH respectively. In vivo inhibition of pollen function by field simulations of acid rain on Oenothera parviflora will be compared to similar inhibition by SO_2 fumigations which have reduced seed set in some species. Given some evidence for correlations between tolerances of the pollen and their sporophytes, the possible effects of direct environmental selection of pollen genotypes on the stigmatic surface by air pollution will be discussed with reference to fitness of future generations.

49. Dendron Resources Surveys Ltd. 1985. Impact of acid rain on forest growth in Canada. Phase I report, prepared for Can. For. Serv., Marit. For. Res. Cent., Fredericton, N.B. (CFS-HQ, CFS-M)

During 1984, work concentrated on the relationship between pollution load and width of annual rings. Data came from unpolluted areas and from the vicinity of an iron sintering plant at Wawa and the smelter of Kidd Creek Mines, north of Timmins. Increment cores from over 700 trees were measured and analysed; the species examined were white spruce, jack pine and balsam fir.

The main goal was to examine the relationship of growth to pollution, and to find methods for providing pollution effects in areas under the influence of the long-range transport of air pollutants (LRTAP).

50. Dendron Resources Surveys Ltd. 1986. Impact of acid rain on forest growth in Canada. Phase II report, prepared for Can. For. Serv., Marit. For. Res. Cent., Fredericton, N.B. (CFS-HQ, CFS-M)

During 1985, the methods developed in Phase I were refined and applied in a survey ranging from western Quebec to Rimouski. Eighteen sample plots were established in groups of three in the vicinity of existing ARNEWS plots, and increment cores were obtained from approximately 800 trees. The species chosen were sugar maple and red and white spruce.

A general pattern of declining growth since 1950-60 was well defined, but other apparently significant but unexplained periods of low growth were observed early in the century.

51. Dendron Resources Surveys Ltd. 1987. Impact of acid rain on forest growth in Canada. Phase III report, prepared for Can. For. Serv., Marit. For. Cent., Fredericton, N.B. (CFS-HQ, CFS-M)

Broad patterns in growth rate were examined using the data from about 2500 trees. A very important result was evidence of low growth rates early in the present century. Growth rates were typically low from 1900 to 1920, and then increased to reach a peak between 1930 and 1960, after which they declined significantly. Current levels are generally as high as or higher than they were at the turn of the century.

Climatic change, insect epidemics tree age and stand development play major roles, and if air pollution is involved then it is almost certainly in complex interaction with other factors.

52. Dignard, N. 1986. Floristic inventory of test plots and observations on their vegetation. (Available only in French.) Research contract with CFS. 40 p. (LFC)

A floristic survey of sample plots was conducted using the Braun-Blanquet technique (1932), modified slightly by Payette and Gauthier (1972). The cover of each layer was evaluated as a percentage, and each species present was rated for abundance-dominance and associativity.

Observations about the health of the upper vegetation may not be absolutely valid because the survey was conducted late in the season (early September). Lesions, scabs and damage to fir needles caused by a type of miner were observed both within and outside the sample plots. These symptoms do not appear to be related to the treatments. However, some comments can be made about the general condition of the vascular plants, particularly woody plants. It is also useful to note that the presence of plants adapted to sun is conditioned by old open areas of various ages in the stand or caused by the establishment of sample plots.

In our view, the only pertinent observations regarding the effect of the various treatments were those made on the state of the bryophyte layer. In fact, this layer appears to have suffered the most damage.

Plots 1, 2, 3, 4 and 6 were not surveyed because they had been partially destroyed by the removal of fir seedlings and by the presence of buried pieces of yellow birch. As a result, it was impossible to assess the percentage of cover, the abundance-dominance coefficients or the state of the vegetation.

The vascular plants and lichens were identified by the author. The bryophytes were identified by Dr. Pierre Masson and Guildo Lavoie from the herbarium of the Ministry of Energy and Resources.

As previously mentioned, the symptoms observed on the vascular plants are probably unrelated to the treatment. The only relevant observations deal with the state of the bryophytes. Plots 28, 41 and 44 appear to be the most affected; plots 10, 13, 15, 45, 46 and 47 are less so; plots 8, 9, 17, 23, 34, 42 and 43 are only slightly affected.

53. English, M.C.; Jeffries, D.S.; Foster, N.W.; Semkin, R.G.; Hazlett, P.W. 1986. A preliminary assessment of the chemical and hydrological interaction of acidic snowmelt water with the terrestrial portion of a Canadian Shield catchment. Water Air Soil Pollut. 30:27-34. (GLFC)

This study examines certain aspects of the hydrological and chemical interaction of springmelt runoff with the terrestrial portion of a Canadian Shield catchment. Though NO_3^- is the dominant anion in the snowpack for most of the winter SO_4^{2-} deposition increases at the end of the winter season (March) such that it is the dominant anion in snowpack meltwater runoff. Pronounced formation of ice lenses in the snowpack are responsible for notable movement of H^+, NO_3^- and SO_4^{2-} ions downslope prior to contact with the ground. Subsurface meltwater flow through the lower portion of the slope is much more acidic (pH 5.18) than that flowing within the subsurface in the upper slope (pH 6.44).

54. FIDS (Forest Insect and Disease Survey). 1984. Forest insect and disease conditions in Canada 1984. For. Insect Dis. Surv., Can. For. Serv., Ottawa, Ont. 76 p. (CFS-HQ)

This report describes the initial results from the Acid Rain - National Early Warning System. The objectives of the program are:

1. to detect the possible damage to forest trees and soils caused by acid rain or to identify the damages sustained by Canadian forests (trees and soils) which are not attributable to natural causes or management practices; and
2. long-term monitoring of vegetation and soils to detect future changes attributable to acid deposition and other air pollutants in representative forest ecosystems.

Permanent plots are maintained in all regions of Canada to monitor:

1. the condition and changes in the condition of the forest stand;
2. the presence and fluctuation of biotic and abiotic factors that affect the condition of the forest (insects, diseases, stand changes, temperature, etc.);
3. the changes and symptoms that indicate factors not attributable to the above that could conceivably be early signs of acid rain damage; and
4. the effects of acid rain on the condition of the various economically important tree species.

55. FIDS (Forest Insect and Disease Survey). 1985. Forest insect and disease conditions in Canada 1985. For. Insect Dis. Surv., Can. For. Serv., Ottawa, Ont. 107 p. (CFS-HQ)

This reports describes the results from the second year of sampling of the Acid Rain National Early Warning System. Descriptions of the observations at sites across Canada are presented. Of particular importance is the identification of the birch deterioration in the Bay of Fundy area of New Brunswick.

56. FIDS (Forest Insect and Disease Survey). 1986. Forest insect and disease conditions in Canada 1986. For. Insect Dis. Surv., Can. For. Serv., Ottawa, Ont. (CFS-HQ)

The Acid Rain - National Early Warning System is updated in this report. Several new sites in Ontario and the Prairies were installed in 1986, and all other plots (104) were re-examined. Maple decline in Quebec and birch deterioration along the Bay of Fundy are described in detail.

57. Fortin, J.A. 1986. Bibliographic study of the main factors involved in forest decline in Europe, the United States, and Quebec. (Available only in French.) Research contract with CFS. 44 p. (LFC)

After devastating many European forests, decline is now appearing in North America. As we now see it, forest decline is a complex disease which leads, through the progressive weakening of the trees, to deterioration and loss of foliage, growth reduction and increased vulnerability to secondary stresses.

Three factors are responsible for the decline: predisposing, inciting and accessory factors. These were classified as physical (climate, soil and human agencies), chemical (atmospheric pollutants) and biological (defoliating insects, fungi) factors. The physical factors do not explain the present phenomenon of constantly worsening damage. The chemical factors represented by atmospheric pollutants, such as sulfur dioxide, nitrogen oxides and ozone, are always present as mixtures, which through a synergistic effect are more toxic than the sum of the various components taken individually. The biological factors play a secondary role only: defoliation may be considered a natural process in the life of a tree, and infestation by certain types of fungus is actually the result of an advanced state of physiological deterioration of affected trees.

Maple groves in Quebec are sometimes situated in poor locations and also in the most highly polluted regions of the province. In view of the most probable causes, forest decline appears to be the result of a set of factors acting together to disturb the balance of the entire forest ecosystem. The response of the ecosystem will differ according to its degree of genetic, physiological and edaphic (soil) resistance. However, if the environmental stress persists, the forest will succumb. Once started, the process of decline becomes generalized and quickly intensifies.

Decline does not yet appear to have affected the productivity of Quebec's conifer forests. However, in light of the situation in Europe and the United States, which has developed catastrophically in the past 25 years, symptoms of decline could soon appear.

It is essential, therefore, to continue studies and simulation experiments so that we can quickly detect the slightest reduction in the yield or quality of our forests immediately and, more importantly, try to remedy the situation.

58. Foster, N.W. 1985a. Acid precipitation and soil solution chemistry within a maple birch forest in Canada. For. Ecol. Manage. 12:215-231. (GLFC)

Ion concentrations in water collected within a hardwood forest at Turkey Lakes Watershed, Ont. (Lat. 47°03'N, Long. 84°15'W) were examined in relation to those in precipitation at the watershed and at other places in eastern Canada. The mean annual concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+, NH_4^+, NO_3^-, SO_4^{2-}, Cl^- and HCO_3^- in precipitation, throughfall, forest floor percolate and mineral soil solution were calculated. The annual flux of H^+, NO_3^-, SO_4^{2-} and base cations was calculated. The annual input of cations by bulk precipitation accounted for 85 and 45%, respectively, of the forest floor fluxes of these ions. The annual flux of H^+ in throughfall was less than that in precipitation. Calcium and Mg^{2+} concentrations in soil solution were highly correlated ($P=0.05$) with NO_3^- during the dormant season, and Ca^{2+} was highly correlated with SO_4^{2-} during the growing season. Both SO_4^{2-} and NO_3^- were largely unreactive with minerals in the Turkey Lakes soil and therefore play a dominant role in cation movement through the soil.

59. Foster, N.W. 1985b. Neutralization of acid precipitation within a maple-birch ecosystem. TAPPI J. 68:104-106. (GLFC)

The influence of acid precipitation on the ionic composition of throughfall, forest floor percolate, and mineral soil solution was examined for a 12-month period within a forest of sugar maple and yellow birch at Turkey Lakes Watershed near Sault Ste. Marie, Ont., Canada. The acidity of precipitation, with an annual volume-weighted pH of 4.4, was reduced 50% by contact with the forest canopy. Acids entering the mineral soil were largely neutralized within base-rich, surface-soil horizons and did not pass through the acid soil into ground or drainage water. Base cation displacement from exchange sites in the soil was associated with neutralization. Bases combined with strong acid anions from the atmosphere and soil and were leached in the drainage water. The effects of such nutrient losses on forest productivity are unknown.

60. Foster, N.W.; Morrison, I.K. 1983a. Soil fertility, fertilization and growth of Canadian forests. Can. For. Serv. Inf. Rep. 0-X-353. (GLFC)

Fertilization test plots have provided the best evidence for assessing soil nutrient-supplying ability in relation to tree demand. Results from experiments in adult forest across Canada and the adjacent United States support the hypothesis that lack of N generally limits growth of some coniferous species, especially on drier sites. Responses to P and K are reported only occasionally; for example, red pine (Pinus resinosa Ait.), on outwash sands abandoned from agriculture, produced 25 to 80 m^3 ha^{-1} of extra wood over 5 to 10 years after fertilization with K. With many species additional growth is realized when P and/or K are added with N, but generally response is not significantly greater than with N alone.

The addition of urea (224 kg N ha^{-1}) to natural stands produced, on average, an additional 15.6 m^3 ha^{-1} of wood over 4 years with Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) and 8.5 m^3 ha^{-1} over 5 years with jack pine (Pinus banksiana Lamb.). In Douglas-fir and jack pine forest, inverse relationships between site index and response to N have been found, the greatest growth increase being on poorer sites. Average 5-year responses were less than those of balsam fir (Abies balsamea (L.) Mill.), red spruce (Picea rubens Sarg.), white spruce (P. glauca (Moench) Voss), and black spruce (P. mariana (Mill.) B.S.P.) (7.1, 4.6, 4.5, and 2.2 m^3 ha^{-1}, respectively).

The use of foliar diagnosis and soil chemical analyses to determine which forests respond to fertilization is discussed.

61. Foster, N.W.; Morrison, I.K. 1983b. Nutrient recycling with respect to whole-tree harvesting in natural stands. Pages 60-65 in D. Robertson, coord. Proc. 6th Int. FPRS Industrial Wood Energy Forum. For. Prod. Res. Soc., Madison, WI. (GLFC)

Increased utilization of biomass during forest harvesting results in greater removal of plant nutrients from the forest site. Nutrient removal associated with conventional (stems-only), full-tree and whole-tree harvesting is compared using a semimature boreal jack pine forest as a case study. The effect of different degrees of utilization on potential future forest productivity is examined. Specifically, stand above- and below-ground biomass and nitrogen contents were calculated by regression equations developed using stem analysis and component nutrient contents from a representative sample of trees. The nitrogen and carbon content of the soil and the cycle of these nutrients from the standing forest to the soil are quantified. The response of the stand to different levels of nitrogen fertilizer is also determined. The above is used to show that nitrogen plays a key role in determining the productivity of this forest. Infertile pine sites should be managed with an aim to conserving nitrogen and carbon reserves. The cost of replacing nutrients removed in harvesting must be considered in any forest management strategy.

62. Foster, N.W.; Morrison, I.K.; Nicolson, J.A. 1983. Acid precipitation--forest ecosystem studies at Turkey Lakes Watershed. For. Res. Newsl., Summer Issue, GLFRC, Sault Ste. Marie, Ont. 8 p. (GLFC)

The maple-birch forests of the Turkey Lakes Watershed are currently being subjected to moderate acid loads from atmospheric sources. Present pollutant loads are generally too low to affect tree growth directly. It is tentatively concluded from preliminary investigations that: 1) the potential nitrogen-supplying capacity in watershed soils is high and atmospheric nitrogen is unlikely to stimulate hardwood growth; and 2) current rates of element leaching are unlikely to cause serious depletion of the content of bases in the tree rooting zone in the short term.

It is not yet possible, however, to determine whether acid precipitation will induce long-term changes in nutrient cycling that will indirectly influence forest productivity. It would appear that sulphate inputs from acid precipitation are likely to produce the most serious long-term changes in nutrient cycling, because of low sulphate adsorption by podzolic soils in the watershed. We know that base losses will increase with further acidification of the soil solution, but we lack sufficient knowledge to predict the rate of soil acidification. Rates of mineral weathering in these soils may not be fast enough to replace bases leached from foliage and exchange sites in the soil.

63. Foster, N.W.; Morrison, I.K.; Nicolson, J.A. 1986. Acid deposition and ion leaching from a podzolic soil under hardwood forest. Water Air Soil Pollut. 31:879-890. (GLFC)

The contribution of atmospheric acids to cation leaching from a podzolic soil under mature maple-birch forest in central Ontario was examined during 1983. The movement of base cations was associated largely with NO_3^-, SO_4^{2-} and organic acid anions in surface soil horizons, with SO_4^{2-} and NO_3^- below the effective rooting zone, and SO_4^{2-} and HCO_3^- in streamflow. Mineral soil horizons could adsorb little additional SO_4^{2-} or associated cations at current soil solution SO_4^{2-} concentrations. Therefore, it is concluded that the soil in situ lacks a strong affinity for SO_4^{2-}. Current annual inputs to the forest of SO_4^{2-} and NO_3^- in bulk precipitation (26.4 and 18.2 kg ha^{-1}, equivalent to 8.8 kg S and 4.1 kg N ha^{-1}, respectively) contributed significantly to cation leaching from the soil. In order to maintain exchangeable cations in soil at current levels, a rate of weathering yielding 29.6, 5.0, 4.4 and 2.2 kg ha^{-1} yr^{-1} of Ca^{2+}, Na^+, Mg^{2+} and K^+, respectively, would be required.

64. Foster, N.W.; Nicolson, J.A. 1983a. Acid precipitation and vegetation interaction in the Turkey Lakes Forest Watershed. Can. For. Serv. Res. Notes 3:6-7. (GLFC)

Concern about the effects of acid rain on forests and water has stimulated renewed interest in how forests and soils alter the quality of precipitation. This report, an interim examination of results from a continuing study of the biogeochemical cycling of elements within a sugar maple (Acer saccharum Marsh.) - yellow birch (Betula alleghaniensis Britton) forest, was presented at the 1982 Conference on Great Lakes Research. The work is part of the Canadian Forestry Service acid rain program examining the influence of acid precipitation on the cycling of elements within three forest catchment basins at Kejimkujik National Park, N.S., Montmorency Forest, Quebec, and Turkey Lakes Forest, Ontario.

65. Foster, N.W.; Nicolson, J.A. 1985. Acid precipitation and water quality within a tolerant hardwood stand and soil. Pages 337-342 in Speeches and Papers, Int. For. Congr. on Forest Resources Management: The Influence of Policy and Law, 7 August 1984, Quebec City, Que. (GLFC)

Soil properties and ion fluxes within a tolerant hardwood forest ecosystem at Turkey Lakes Watershed, Ontario, were examined to identify whether acid precipitation could contribute to the leaching of base cations from vegetation and soil. At the watershed the amount of SO_4^{2-}, NO_3^- and H^+ deposited by bulk precipitation was 25.5, 20.4 and 0.5 kg ha^{-1}, respectively, in 1982. Hydrogen was retained largely within the terrestrial ecosystem and did not appear in streamwater. Precipitation removed base cations from the forest canopy and from the surface soil horizons. Base cation leaching was associated with a mix of anions (organic acid, SO_4^{2-}, NO_3^- and HCO_3^-) in the forest floor and surface mineral horizons, with SO_4^{2-} at the lower limit of tree rooting, and with HCO_3^- and SO_4^{2-} in the subsoil and groundwater zones. Geochemical weathering of cations in the subsoil contributed significantly to the base cation composition of streamflow. The content of exchangeable base cations in the surface 0.5 m of soil exceeded by 100 times the annual quantity of base cations that could be leached by current atmospheric SO_4^{2-} deposition. Acid precipitation at present levels, therefore, is unlikely to produce short-term base cation degradation of this soil.

66. Foster, N.W.; Nicolson, J.A. 1986. Trace elements in the hydrologic cycle of a tolerant hardwood forest ecosystem. Water Air Soil Pollut. 31:501-508. (GLFC)

The concentrations and annual fluxes of Fe, Al, Mn, Cu and Pb were measured during 1983 in bulk precipitation, throughfall, stemflow, forest floor percolate, mineral soil solution below the root zone and streamflow in a maple-birch stand on an acid podzolic soil at the Turkey Lakes Watershed (TLW), Ontario. Inputs of metals to TLW in precipitation were small in comparison with those in the eastern United States and Europe. Considerable loss of Mn and Cu from the vegetation during both the growing and the dormant (leafless) periods was observed and presumed to be due to leaching. The enrichment in soil solution of all metals examined, in relation to throughfall, was greatest for Al (7X) and least for Cu (1.2X). Aluminum was mobilized in both the forest floor and the mineral soil, the latter possibly in association with SO_4^{2-}. Copper was solubilized in the lower forest floor or the mineral soil. Surface soil contents of Al and Cu were reduced by Al and, to a lesser extent, Cu leaching beyond the effective rooting zone. Iron, Mn and Pb were mobilized largely in the F horizon of the forest floor, most likely by organic acids. Leaching of Fe, Mn and Pb was reduced by metal accumulation in vegetation, the lower forest floor, or mineral soil within the effective rooting zone of the vegetation. Most (80 to 99%) of the metals leached from the rooting zone were retained in the watershed and did not appear in streamwater.

67. Foster, N.W.; Nicolson, J.A. 1988. Ion transfer through a tolerant hardwood canopy, Turkey Lakes Watershed, Ontario. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (GLFC)

Hydrogen (H), potassium (K), calcium (Ca), nitrate-N (NO_3-N) and sulphate-S (SO_4-S) were measured, during 1981, outside and within an old-growth sugar maple (Acer saccharum Marsh.) - yellow birch (Betula alleghaniensis Britton) forest growing on an acid till soil at Turkey Lakes Watershed, Ontario. Mean concentrations and contents of elements in precipitation, throughfall and stemflow were compared on an annual, growing season and dormant season basis. Throughfall solutions were similar to precipitation in ionic composition, with the exception of K in bases and SO_4-S during the growing season. Stemflow solutions were highly enriched in Ca, K, and SO_4-S, and depleted in H and NO_3-N, during both periods. Throughfall was the major process of element transfer to soil; stemflow accounted for only 1 to 10% of the total annual deposition of each element in the soil. The role of H in promoting base leaching from the forest canopy is discussed in relation to other eastern North American tolerant hardwood forests, which are more heavily impacted with acid precipitation.

68. Foster, N.W.; Nicolson, J.A.; Morrison, I.K. 1988. Acid precipitation and element cycling in eastern North American forest ecosystems. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (GLFC)

Current knowledge of the relationship between atmospheric deposition of acids and acid-forming substances on the one hand and element fluxes on the other in major eastern North American forest types is reviewed. A mature tolerant hardwood forest on a well-drained acid till soil in Turkey Lakes Watershed in northern Ontario serves as a point of reference. Nitrogen (N) and sulphur (S) fluxes between element pools within the ecosystem are emphasized because of the association of N- and S- forms with acid pollution. Nitrogen turnover (ca 45 kg ha^{-1} yr^{-1}) in the reference forest ecosystem is much greater than atmospheric N turnover (7 kg ha^{-1} yr^{-1}). Thus, a tight cycle of N is maintained in this undisturbed old-growth hardwood forest. Input/output of sulphate-S (SO_4-S) in the watershed is roughly in balance. Sulphate concentrations are equal to 70% of the total base cation concentrations, on an equivalent-weight basis, in soil water below the rooting zone of the reference forest. At current levels, atmospheric inputs of SO_4-S contribute significantly to losses of base cations (potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na)) from the rooting zone of many eastern ecosystems. A reduction in the quantity of SO_4-S entering eastern forest soils would likely reduce cation losses from these ecosystems.

69. Fraser, G.A.; Phillips, W.E.; Lamble, G.W.; Hogan, G.D.; Teskey, A.G. 1985. The potential impact of the long range transport of air pollutants on Canadian forests. Can. For. Serv. Inf. Rep. E-X-36. 29 p. (CFS-HQ, GLFC)

The effect of the long range transport of air pollutants (LRTAP) on forests is uncertain. A definitive scientific answer will require extensive scientific research over a period of years. In the interim, this study sheds considerable light on the potential effects. Using an iterative series of four questionnaires, expert opinion was solicited on the nature and extent of forest productivity change and the likelihood of alternative forest productivity effects under several different pollution scenarios. The results provide a realistic picture of the risk to Canadian forests from present and potential future levels of pollution.

70. Germida, J.J.; Maynard, D.G.; Addison, P.A. 1985. Effect of elemental sulfur deposition on populations of sulfur-oxidizing microorganisms in forest soils. Can. Soc. Microbiol. Annu. Meet., Halifax, N.S. (NoFC)

Elemental sulfur is a by-product of scrubbing sour natural gas. Mechanical breakup and weathering of S blocks have eliminated vegetation in localized forest areas adjacent to gas plants. This study assessed the effect of long-term S pollution on selected chemical and biological components of forest soil. In 1982 and 1983, soil samples were collected at sites 50, 250 and 750 m from a S block. Samples were analyzed for total-S, SO_4-S, elemental S, pH, and populations of S-oxidizing microorganisms. A significant decrease in soil pH (4.8 to 2.5) and an increase in elemental S (6000 to 50 000 ppm) occurred with increasing proximity to the S block. Total-S and SO_4-S exhibited a trend similar to elemental S. There was no significant difference between years. All soils contained significant populations of autotrophic thiobacilli that were 1000 to 10 000-fold higher than in unpolluted soils. Heterotrophic S-oxidizing microbes were also detected in these soils, although there was a shift from a mixed, S-oxidizing community in 1982 to one dominated by autotrophic thiobacilli in 1983. These results show that elemental S-polluted forest soils contain active populations of S-oxidizing autotrophic thiobacilli that are responsible for soil acidification.

71. Glass, N.R.; Glass, G.E.; Rennie, P.J. 1979. Effects of acid precipitation. Environ. Sci. Technol. 13:1350-1355. (CFS-HQ)

In summary, there is substantial reason to suspect that the deposition of acidic precipitation, especially in wide geographic areas of the eastern U.S. and Canada, will have adverse effects on aquatic systems, forests, and agricultural systems. The latest evidence suggests several avenues of research which should be pursued to define further the magnitude and extent of the effects of acid precipitation on resources.

The cumulative threat of acid precipitation is recognized, and a concerted attack is being spearheaded by Environment Canada and the U.S. Environmental Protection Agency (EPA) that brings together different disciplines and jurisdictions. Ongoing pollution studies, based on strong point emitters, and special new investigations are being applied in a number of promising approaches. These include the use of sensitive lichens as indicator species, pre-visual biochemical tests on tree and other plant tissues, differential depositional patterns of pollutants on soils, and delineation of "sensitive" soils, forests and water bodies.

72. Glass, N.R.; Glass, G.E.; Rennie, P.J. 1980. Effects of acid precipitation in North America. Environ. Int. 4:443-452. (CFS-HQ)

Recent evidence indicates that acid rain is a growing environmental phenomenon of potentially far-reaching consequences and increasing geographical extent in North America. Acid rain is but one aspect of the broader problem of atmospheric deposition which includes snow, fog, and dry deposition of material. First noticed and studied in the Scandinavian countries, acid precipitation has now been well documented in the United States, first in the northeast and more recently throughout much of the United States east of the Mississippi River. Numerous streams and lakes in regions with poorly buffered soils have become devoid of fish, have an impoverished aquatic flora and fauna, and are changing toward conditions of low aquatic productivity. Evidence also indicates that acid precipitation may cause damage to forest growth, crop production, wildlife, and man-made materials such as buildings, metals, paints, and statuary.

73. Halstead, R.L.; Rennie, P.J. 1977. The effects of sulphur on soils in Canada. Pages 181-219 in Sulphur and its inorganic derivatives in the Canadian environment. Associate Committee on Scientific Criteria for Environmental Quality, Natl. Res. Counc. Can., Ottawa, Ont. Publ. No. 15015. 426 p. (CFS-HQ)

The amount of research on the effects of sulphur dioxide on the soil is limited, relative to the published work on its effects on plants. This is undoubtedly due to the fact that in most instances the addition of atmospheric sulphur to the soil contributes to the plants' available supplies of this nutrient. Nevertheless, it is well known that sulphur dioxide pollution of soils for prolonged periods will result in an increase in acidity and in soluble sulphate content of the soil with a reduction in calcium and other bases, reduced activity of microorganisms (particularly nitrifiers and nitrogen-fixers), increased concentration of potentially toxic ions (aluminum, manganese), reduction in availability of other nutrients (phosphorus), and an overall greater contribution of nutrients and potentially hazardous ions to surface and ground waters. Perhaps one of the most serious hazards arising from excessive atmospheric additions of sulphur dioxide is that of soil erosion following the death of the vegetative ground cover. This aspect of the problem has not been adequately considered in this document or in any of the reports devoted to this problem. There is an obvious need for research on this problem--particularly in relation to the contribution of erosion to the pollution of surface waters. On the basis of our present knowledge, there is little question that new studies are required to determine the mechanisms and rates of chemical weathering in soil systems dominated by sulphuric acid. The impact of these weathering processes on the productivity of the soil for production of agricultural and forest crops, as well as the effects on the associated biosystems, should be determined. Specific areas of concern include the following:

1. The role and importance of soil microorganisms in the soil sulphur cycle--mechanism of oxidation by Thiobacillus spp., role of heterotrophs in sulphur oxidation, transformations of organically combined sulphur from the point of view of retention and availability, rhizosphere and sulphur oxidation.

2. The implementation of field, greenhouse and lysimeter studies to quantify the movement of native and applied sulphur and associated ions in the soil and plant systems. These studies would aid in the achievement of optimum production with minimum environmental consequences. In agricultural and non-agricultural areas, the information would enable environmental protection agencies to provide realistic regulations governing the use and emission of sulphur and its compounds.

74. Hargesheimer, E.E.; Apps, M.J.; Malhotra, S.S. 1980. Determination of vanadium in jack pine needles using neutron activation analysis. Environ. Tech. Lett. 1: 273-282. (NoFC)

The potential for mapping certain types of industrial pollution by the measurement of vanadium in jack pine needles has been investigated. A rapid instrumental neutron activation method for the analysis of V, Al, Ca, Na, Mn, and Cl at parts per million concentrations in jack pine needles has been developed with the SLOWPOKE nuclear reactor. Detection and determination limits (Currie 1968) for vanadium in 100 mg of ground needle tissue were 0.36 ppm and 1.6 ppm, respectively.

75. Harrington, J.B. 1987. Climatic change: a review of causes. Can. J. For. Res. 17:1313-1339. (PNFI)

The earth's climate is constantly changing. Climatic change is effected by many factors: the influence of continental drift, variations in solar intensity, volcanism, the impact of meteors and comets, changes in the earth's orbital parameters, ice accumulation and depletion, variations in oceanic circulations and chemistry, changes in terrestrial and aquatic life, and changes in atmospheric composition and circulation. Despite these influences, many of them large, and despite changes in the sun's radiant intensity over the past 4.5 billion years, the average temperature of the earth's surface has remained remarkably constant, hovering near 15°C. This implies the presence of strong negative feedbacks reacting to any major environmental change. During the past century, man's influence on his environment has been increasing at an unprecedented rate. Under this influence, and particularly because of the effect of the so-called "greenhouse gases," the global mean temperature is expected to rise approximately 2.5°C by the middle of the 21st century. There remains a degree of uncertainty in this prediction because of unresolved problems in estimating various positive and negative feedback mechanisms in air, earth, ocean, ice, and vegetation interaction and in the unknown magnitude of volcanic activity. The finest numerical models and the fastest computers are, at present, inadequate to resolve all of the problems. However, the best scientific evidence points to a return by the middle of the 21st century to a climate similar to that of the climatic optimum 5000-6000 years ago. The degree of confidence in the direction, speed, and magnitude of the impending climatic change is sufficient that affected agencies should be actively mapping strategies to respond most advantageously to the expected changes. This is particularly true of forestry in Canada where climatic changes are expected to be large and the lifetime of current plantings will extend well into the period of anticipated change.

76. Hay, G.W.; James, J.H.; vanLoon, G.W. 1985. Solubilization effects of simulated acid rain on the organic matter of forest soils: preliminary results. Soil Sci. 139:422-430. (GLFC)

We determined the concentrations of total organic carbon, total carbohydrate, fulvic acid, and ammonium-plus-amino nitrogen in leachates from columns of a Canadian Shield podzol soil at depths of approximately 10 and 20 cm after treatment with aqueous solutions of pH 5.7, 3.5, and 2.0. Sampling was carried out in the laboratory over a 16-d period during which the soil received a total accumulation of 935 mm of simulated rainfall, equivalent to 1 year's precipitation. Highest concentrations of each of total organic carbon, total carbohydrate, and fulvic acid were obtained after the pH 5.7 treatment; the concentrations were greater at the 10-cm depth than at 20 cm. The pH 2.0 solution dissolved the least amounts of these components. The opposite trend was observed in the analyses of ammonium-plus-amino nitrogen. The soil exhibited considerable buffering action in terms of regulating leachate pH.

77. Hern, J.A.; Rutherford, G.K.; vanLoon, G.W. 1985. Chemical and pedogenetic effects of simulated acid precipitation on two eastern Canada forest soils. 1. Non-metals. Can. J. For. Res. 15:839-847. (GLFC)

An experiment involving the addition of simulated acid rain on two Canadian Shield orthic humo-ferric podzolic forest soils was carried out in the field and in the laboratory. Soils were subjected to treatments of pH 5.7, 3.5, and 2.0 water containing added nitric and sulphuric acids in a 1:2 molar ratio. Pore-water concentrations of H^+, NH_4^+, NO_3^-, SO_4^{2-} and Cl^- were monitored at depths of 15-60 cm for up to 2 years. Some of the laboratory columns were dismantled after 1 year and total soil, N, S, soil pH, and S adsorption characteristics were measured. Half the columns were sterilized in an attempt to assess the relative importance of microbial processes. Considerable H^+ buffering by the soils was indicated, with soil pH unchanged even under the most acidic treatment. Nitrate but not ammonium production was suppressed under highly acid treatment conditions in the laboratory, while in the field only small concentrations of both nitrogen species were detected in pore water. No change in total soil N was detected. Sulphur retention was assessed, with major amounts retained by the soil just below the Ae horizon where iron and aluminum oxides along with organic matter accumulate. Sterile column data indicate microbial processes are also of considerable importance in the immobilization of S inputs.

78. Hern, J.A.; Rutherford, G.K.; vanLoon, G.W. 1988. Effects of simulated acid rain on the cation exchange capacities of two podzolic soils. Geoderma (in press). (GLFC)

A laboratory column experiment was performed in which reconstructed profiles of a Humo-ferric and a Ferro-humic Podzolic soil were leached with simulated acid rain for two years. In order to assess the effects of treatment on the cation exchange capacity, the columns were sampled and negative charge of the soil was measured. Water- and phosphate-extractable sulphate, organic carbon content and non-silicate iron and aluminum were also determined. Negative charge was correlated with organic carbon in the organic horizons, but there was no significant effect due to treatment. A small decrease in negative charge with increasing acidity of treatment was observed in the B horizons of both soils, although the change was significant at the 95% confidence level only for the Humo-ferric Podzol.

79. Hocking, D.; Hocking, M.B. 1977. Equilibrium solubility of trace atmospheric sulfur dioxide in water and its bearing on air pollution injury to plants. Environ. Pollut. (Ser. A) 13:57-64. (NoFC)

Experimentation with and understanding of sulfur dioxide injury to plants may be improved with better knowledge of the chemical dynamics of sulfur dioxide dissolution. This paper computes curves of chemical equivalence between SO_2 in air and in water, over the range of temperatures and SO_2 concentrations in air that bracket those for injury to plants; tabulates relationships among the ionic and molecular species that occur; and finds excellent agreement with the fragmentary experimental data that exist. On the basis of the results and data in the literature, it is inferred that dissolved but unreacted SO_2 is the most active species for initial plant injury in air pollution episodes.

80. Hogan, G.D.; Maynard, D.G. 1985. Sulphur analysis of environmental materials by vacuum inductively coupled plasma atomic emission spectrometry (ICP-AES). Pages 676-683 in Proc. Sulphur '84 Int. Conf., June, Calgary, Alta. Sulfur Dev. Inst. Can., Calgary, Alta. (GLFC, NoFC)

The determination of sulfur (S) in environmental materials has always been a source of frustration. The methods used have been inconvenient or unreliable because of poor precision, interference caused by competing ions, lack of sensitivity, and a small dynamic range. Inductively coupled plasma atomic emission spectrometry (ICP-AES) has received considerable attention as a valid technique for the determination of S in steel when the appropriate operating conditions are met. It has not, however, been widely acknowledged as a useful method for environmental materials. Sulfur emission lines in the ultraviolet (180.7 nm) can be used to quantify S in environmental materials. The chief advantages of the technique are high sample throughput (20-30 samples per h), good detection limits (0.1 mg L^{-1}), and broad dynamic range (linear to 1000 mg L^{-1}).

The precision of the S determinations using ICP is presented for sediments, plant materials and stream samples. The recovery of S from these materials and the accuracy of measurements were tested with standard additions and comparisons with uncertified United States National Bureau of Standards (NBS) standards for orchard leaves and estuarine sediments. The mean S concentrations, standard deviations, and percentage recovery for the orchard leaves and estuarine sediment were 2022 ± 44 (106%) and 10540 ± 203 (111%), respectively. Comparisons were also made between S values determined by ICP-AES and by conventional methods on selected samples (i.e. Johnson and Nishita apparatus and ion chromatography).

81. Hogan, G.D.; Morrison, I.K. 1988. Distribution of trace metals within the aboveground phytomass of Acer saccharum and Betula alleghaniensis in the Turkey Lakes Watershed. Can. J. Fish Aquat. Sci. (in press). (GLFC)

A study of manganese, iron, zinc, copper, lead, nickel, and cadmium distribution in Acer saccharum Marsh. (sugar maple) and Betula alleghaniensis Britt. (yellow birch) was carried out at the Turkey Lakes Watershed (TLW) in the District of Algoma, Ontario. Aboveground phytomass was dominated by stemwood (134 200 kg ha^{-1}), stembark (19 300 kg ha^{-1}) and branches >2 cm (38 800 kg ha^{-1}). Acer saccharum was the dominant species, accounting for 88% of the aboveground phytomass. The generalized phytomass trace metal concentration series for A. saccharum was Mn>Fe>Zn>Cu>Pb>Ni>Cd, and for B. alleghaniensis Mn>Zn>Fe>Cu>Pb>Ni>Cd. Concentrations of metals were highest in the foliage or stembark and lowest in stemwood but, because of its large mass, stemwood generally contained the greatest amount of metal per tree and per hectare. Components of B. alleghaniensis contained higher Zn and Cd concentrations than did those of A. saccharum by a factor of between five and ten, an indication that B. alleghaniensis is an accumulator of these metals. Lead levels in all components were one-third to one-half those reported elsewhere, a reflection of lower deposition at TLW. Historical data from other sites in North America gave no indication that concentrations of essential trace metals in aboveground components were higher than normal for these species.

82. Hogan, G.D.; Wotton, D. 1984. Pollutant distribution and effects in forests adjacent to smelters. J. Environ. Qual. 13:377-381. (NoFC)

Pollutant levels were examined in a boreal forest system that had been exposed to smelter effluents for 50 yr. High levels of Zn, Cu, and Pb were found in the surface soils close to the source (<10 km) and declined rapidly in a south-southeast direction. Significant deposition of metals may be occurring at sites up to 35 km from the source. Positive correlations between metals found in the soil and distance from the source implicated the smelter as the source of the metal particulates. The most heavily impacted sites (>4000 and 1000 mg kg^{-1} of Zn and Cu respectively) showed significant accumulations of metal at lower depths. Extraction of soils with diethylenetriaminepenta-acetic acid (DTPA) indicated that 50 to 60% and 18 to 36% of the Zn and Cu, respectively, could be in a plant-available form. Soil pH was not related to distance from the source, indicating that acidification had not taken place; this was confirmed by snow analysis. Data did not indicate that metal levels in the soil have affected the foliar nutrient levels of major tree species. Elevated S levels were found in the foliage of black spruce (Picea mariana Mill.) close to the source but were not apparent for jack pine (Pinus banksiana Lamb.).

83. Holowacz, J. 1985. The forests and the new forest injury in the Federal Republic of Germany. For. Chron. 61:262-266. (CFS-HQ)

The new forest injury in the Federal Republic of Germany is defined as a complex disease caused by a multiplicity of factors in which air pollution plays a major role. Since 1982, one reconnaissance and two comprehensive forest injury inventories have been carried out. The data from the latest (1984) inventory show that over 50% of the country's forested area has been affected by this new forest injury. Conifers tend to be more severely affected than hardwoods, and trees older than 60 years are more likely to be injured than the younger ones. The consequences of the injury are manifesting themselves in a drastic reduction of growth as well as mortality of, so far, individual trees. A forced removal of "calamity timber" is resulting in the creation of unplanned openings and a distortion of age class distribution. A further spread of the injury, both in area and in intensity, will make the Federal Republic even more dependent on foreign timber supplies and, in the process, change the appearance of the German landscape.

84. Huebert, D.B.; L'Hirondelle, S.J.; Addison, P.A. 1985. The effects of sulfur dioxide on net CO_2 assimilation in the lichen Evernia mesomorpha Nyl. New Phytol. 100:643-651. (NoFC)

Physiologically active thalli of the lichen Evernia mesomorpha Nyl. were very sensitive to short-term fumigations with low concentrations of gaseous sulfur dioxide. Net CO_2 assimilation rate (NAR) was significantly reduced after exposure to 0.085 $\mu L\ L^{-1}\ SO_2$ for 1 h or more and the reduction increased with increasing concentration. Duration of exposure had no significant effect on NAR, indicating the importance of SO_2 uptake rate rather than the total amount absorbed. Respiration was significantly reduced after 4 h or more of exposure to 0.265 $\mu L\ L^{-1}$ SO_2 or higher. Recovery of NAR after fumigation was dependent on both SO_2 concentration and duration of fumigation, and on the time allowed for recovery. Virtually complete recovery occurred within 24 h after episodes with up to 0.355 $\mu L\ L^{-1}$ SO_2 for 1 h and 0.085 $\mu L\ L^{-1}$ for 4 h. Above these levels, recovery was incomplete or nonexistent after 24 h in clean air. The level of sensitivity found can be attributed to the environmental conditions during fumigation, which prevented thallus desiccation and inactivity. Based on this study, neither the concept of dose (concentration X time) nor that of 'threshold' levels of SO_2 fumigations is supported. Peak exposures to SO_2 for short periods may be of primary importance in determining the survival of lichens in industrial areas and particularly around point sources such as oil sands plants.

85. Hutchinson, T.C. 1985. A comparative study of the toxicity of aluminum to seedlings of five coniferous species. Report of contract 25SV KH405-2-0153, Univ. Toronto, Toronto, Ont. 33 p.; figs.; tables. (GLFC)

The purpose of this study was to examine the response of seedlings of a number of economically important species to a range of Al exposures, with varied Ca or Mg concentrations. The findings of the present study are that all 5 species of conifer, as seedlings, show some tolerance to elevated Al levels. The growth response is sometimes linear and reductions commence with even small (5 ppm) occurrences of Al. White pine was much the least sensitive to Al, while red spruce was the most sensitive at low levels of Al. White pine tolerated 20 ppm Al with no decreased growth, and with only a small reduction at 40 ppm, while red spruce was reduced 50% in growth at 51 ppm Al. Black spruce was less sensitive than red at 5 and 10 ppm Al but then showed a rapid decrease in growth with increasing Al. White spruce was much more tolerant than the other two spruce. The high Ca level used (i.e. 16 ppm) was too low to be an effective antagonist of the higher Al levels used as treatments. It certainly seems probable that Ca and Mg act to ameliorate Al toxicity and that the forms of Al in the soil are also essential factors in determining its toxicity.

86. Hutchinson, T.C.; Bozic, L; Munoz-Vega, G. 1986. Responses of five species of conifer seedlings to aluminum stress. Water Air Soil Pollut. 31:283-294. (GLFC)

Seedlings of red, white and black spruce and white and jack pine were tested for their response to a range of Al concentrations, when grown for 12 to 14 weeks in sand culture in the greenhouse. Nutrients were supplied in solution of pH 3.8 to which Al was supplied at 0, 5, 10, 20, 40, 80 and 160 mg L^{-1}. Red and white spruce were inhibited in growth from 5 mg L^{-1} upwards, while black spruce was equally inhibited only at concentrations >20 mg L^{-1}. In contrast, white pine was stimulated by 5 to 20 mg Al L^{-1} and was always more tolerant than the other 4 species at every Al level used. Jack pine was intermediate in its response. There was a positive linear relationship between P and Al accumulation in the shoots of red spruce. This was in contrast to the other 4 species in which P concentrations in the shoot decreased with an increase in Al concentrations. In localization studies on jack pine using a modified hematoxylin stain, Al was shown to accumulate in the root cap of root tips, and in the epidermal and outer cortical walls of older roots. EDAX-SEM analysis confirmed the tissue distribution of Al and revealed its coincidental distribution with P in roots.

87. Jeffries, D.S.; Semkin, R.G.; Neureuther, R.; Seymour, M.; Nicolson, J.A. 1986. Influence of atmospheric deposition on lake mass balances in the Turkey Lakes Watershed, central Ontario. Water Air Soil Pollut. 30:1033-1044. (GLFC)

Ion mass budgets were measured for 2 water yr (June-May, 1981-83) for a high and a low elevation lake and their associated catchments. The lakes are located in the Turkey Lakes Watershed (TLW) in central Ontario, Canada, which is an undeveloped basin located on the Canadian Shield, 50 km north of Sault Ste. Marie. The ionic budgets of the lakes show that atmospheric deposition directly to the lakes' surfaces is the principal input pathway for H^+ and NH_4, whereas basic cations, SO_4, NO_3, and probably alkalinity are supplied primarily by inflow from the surrounding terrestrial basin and/or upstream lake. The lakes strongly retain H^+ (i.e. output << input), weakly retain the N species, and are in balance (i.e. output = input) for other ions except Ca and alkalinity which show an excess output compared to measured + estimated inputs. We hypothesize that an input of groundwater and/or seepage accounts for most of the Ca and alkalinity imbalance although the existence of within-lake alkalinity generation is probable also.

88. Joshi, S.R. 1982. Airborne radioactive materials and plants: a review. Sci. Total Environ. 24:101-117. (NoFC)

Airborne radioactive materials readily contaminate plant surfaces and thus are incorporated into food chains. Most of the nuclear fission products and naturally occurring radionuclides in the air are carried on solid particles ranging in size from a few submicrons to several millimetres in diameter. Of many available mechanisms, rainfall plays a dominant role in the deposition and removal of radioactive particles from plants. Mechanisms for the deposition of submicron particles, which carry significant amounts of radioactivity, are still not very well understood.

Available information on the physicochemical aspects of the retention of radionuclides by plants is inadequate in explaining radionuclide uptake and desorbability. Much of the work reported so far has been carried out on selected fission products only. There is a dearth of data pertaining to naturally occurring radionuclides, especially ^{222}Rn and its daughters, significant amounts of which are released to the environment during uranium mining and milling operations. Radiation damage in plants is difficult to detect except at levels of contamination thousands of times higher than those attained in real-life situations. Existing reports give conflicting accounts of the damage induced by low-level radiation in plants.

The literature data discussed in this review are presented as basic information needed for the conduct and interpretation of useful research.

89. Kennedy, K.A.; Addison, P.A. 1985. Some considerations for the use of visual estimates of plant cover in biomonitoring. J. Ecol. 75:151-157. (NoFC)

The magnitude of changes required to detect air pollution effects was determined by an error analysis of visual estimates of plant cover in a Pinus contorta Loudon var. latifolia Engelm. stand in western Canada. Species with the greatest measurement errors had either a large amount of wood in relation to the amount of leaf, compound leaves, or were identified incorrectly. The observer's familiarity with the vegetation enhanced measurement precision while the removal of species with large measurement error (>20%) had little effect on the similarity of repetitive measurements. The time of year of vegetation sampling influenced the results. Sampling between mid-June and mid-August, when there was minimal change in the vegetation, virtually eliminated this source of error. Changes in the vegetation need to be >20% before they can be attributed to factors other than annual variation and measurement error.

90. Kennedy, K.A.; Addison, P.A.; Maynard, D.G. 1985. Effect of particulate elemental sulfur on moss. Environ. Pollut. (Ser. A) 39:71-77. (NoFC)

The influence of particulate elemental sulfur on the moss component in stands of Pinus contorta Loudon var. latifolia Engelm. (lodgepole pine) in west-central Alberta was examined. Mosses were eliminated from the first 30-60 m of forest adjacent to the source. Downwind of this zone, the percentage of moss alive increased linearly with distance from the source, and 46% of the variance in the percentage of moss alive was accounted for by a regression on total sulfur content of the litter (surface organic layer of the forest floor). Total sulfur and elemental sulfur concentrations in the litter were significantly related to each other and decreased logarithmically with distance from the source. The pH of the litter did not appear to provide a good representation of pollutant deposition. The percentage of moss alive and the total sulfur content of the litter are proposed as a suitable technique for indicating the impact and extent of elemental sulfur contamination of logdepole pine forests in the foothills of Alberta.

91. Kennedy, K.A.; Addison, P.A.; Maynard, D.G. 1987. Effect of elemental sulfur on vegetation. Environ. Pollut. 51: 121-130. (NoFC)

Shrub and herb cover decreased 98% and species diversity 76% in a *Pinus contorta* Loudon var. *latifolia* Engelm. forest subject to elemental sulfur deposition. Decreases occurred over five years and, initially, were greater for the herbs than they were for the shrubs. The decline in the herbs occurred one year before decreases in half the shrub species. The plants' response was related to the acidification of the soil as the sulfur oxidized.

92. Khan, A.A.; Malhotra, S.S. 1977. Effects of aqueous sulfur dioxide on pine needle glycolipids. Phytochemistry 16:539-543. (NoFC)

The major glycolipids in the fully developed and young needle tissue of lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) were monogalactosyl diglyceride (MGDG), digalactosyl diglyceride (DGDG), and sulfoquinovosyl diglyceride (SQDG). The concentration of these glycolipids was considerably higher in the fully developed needles than in the young needles. The major fatty acid in the MGDG fraction (from both tissues) and DGDG fraction (from fully developed tissues) was linolenic acid. However, palmitic acid was the major fatty acid in the DGDG fraction from the young tissues and the SQDG fraction from both tissues. Treatment of needles with aqueous SO_2 solutions produced marked changes in the concentration and composition of these glycolipid fractions. At 100 ppm, SO_2 produced a considerable drop in the linolenic acid content of all glycolipid fractions, more pronounced in the young needles than in the fully developed ones. SO_2 also had an effect on the release of soluble sugars from the needle tissues of both ages.

93. Khan, A.A.; Malhotra, S.S. 1978. Biosynthesis of lipids in chloroplasts isolated from jack pine needles. Phytochemistry 17: 1107-1110. (NoFC)

Suspensions of isolated pine needle chloroplasts were shown to incorporate galactose from UDP galactose-[^{14}C] into galactolipids. The incorporation of the label among galactolipids was always considerably higher in the monogalactosyl diglycerides than in the digalactosyl diglycerides. The galactosyl incorporation into both galactolipid fractions was optimal at pH 8.0 and was inhibited by sulfhydryl reagents (p-chloromercuribenzoate, N-ethylmaleimide and $CdCl_2$). The chloroplast preparations were also able to biosynthesize various phospholipids and galactolipids from palmitoyl-[1-^{14}C]-CoA; the major portion of the label appeared in phosphatidyl choline. The incorporation of palmitic-[1-^{14}C] acid into various lipids was very poor compared to that of palmitoly-[1-^{14}C]-CoA. However, addition of ATP and CoA markedly stimulated lipid biosynthesis from palmitic-[1-^{14}C] acid, suggesting the presence of activating enzymes. These chloroplast suspensions did not show any de novo fatty acid synthesis.

94. Khan, A.A.; Malhotra, S.S. 1982a. Ribulose biphosphate carboxylase and glycollate oxidase from jack pine: effects of sulfur dioxide fumigation. Phytochemistry 21:2607-2612. (NoFC)

Ribulose biphosphate (RuBP) carboxylase and glycollate oxidase were partially purified from jack pine (Pinus banksiana Lamb.) needles. Preincubation of RuBP carboxylase with HCO_3^- and Mg^{2+} markedly stimulated its activity. RuBP carboxylase showed hyperbolic reaction kinetics with respect to HCO_3^-, Mg^{2+} and RuBP. Both SO_3^{2-} and SO_4^{2-} inhibited RuBP carboxylase, but SO_3^{2-} was more inhibitory than SO_4^{2-}. The SO_3^{2-} inhibition was competitive with respect to HCO_3^- (whether SO_3^{2-} was present during activation or was added to the activated enzyme), while SO_4^{2-} inhibition was non-competitive with respect to HCO_3^-. Glycollate oxidase was inhibited more severely by low concentrations of SO_3^{2-} than by SO_4^{2-}. Fumigation of jack pine seedlings with 0.34 ppm sulfur dioxide for 24 and 48 h produced a considerable decline in the activities of these enzymes, but 1 h of fumigation produced no effect. During the longer exposures, the sulfur content of the needles increased considerably, although the needles showed no visible injury. It is suggested that the accumulation of SO_3^{2-} and SO_4^{2-} in the needles following sulfur dioxide exposure influenced the enzyme activities.

95. Khan, A.A.; Malhotra, S.S. 1982b. Peroxidase activity as an indicator of SO_2 injury in jack pine and white birch. Biochem. Physiol. Pflanzen 177:643-650. (NoFC)

Peroxidase (EC 1.11.1.7) activity in jack pine and white birch seedlings increased greatly during aging of the foliar tissues. Fumigation of seedlings with SO_2 caused a marked increase in enzyme activity and sulfur content of both species; these responses were, however, more pronounced in white birch than in jack pine. The stimulation of peroxidase in SO_2-fumigated jack pine seedlings appeared to be due to increased production of the peroxidase isoenzymes rather than their activation. Increase in both peroxidase activity and sulfur content in the fumigated tissues appeared to be transitory in nature as shown by their decline during recovery in an SO_2-free atmosphere. A possible role of peroxidase in SO_2-initiated free radical process is discussed.

96. Khan, A.A.; Malhotra, S.S. 1983. Protein biosynthesis in jack pine and its inhibition by sulfur dioxide. Phytochemistry 22:1325-1328. (NoFC)

Incorporation of (U-^{14}C) leucine in jack pine (Pinus banksiana Lamb.) occurred mainly in the chloroplast and soluble cytoplasmic fractions. In the chloroplasts, a major portion of the label was associated with the membrane-bound proteins. Fumigation of pine seedlings with gaseous SO_2 (0.34 ppm) for 24 and 48 h markedly inhibited de novo protein biosynthesis in the chloroplast and cytoplasmic fractions. The inhibition was greater in the biosynthesis of chloroplast proteins than in the cytoplasmic ones. The magnitude of inhibition was dependent on exposure time and appeared to be related to sulfur uptake in the treated tissues.

97. Khan, A.A.; Malhotra, S.S. 1987. Effects of vanadium, nickel and sulphur dioxide on polar lipid biosynthesis in jack pine. Phytochemistry 26:1627-1630. (NoFC)

Biosynthesis of polar lipids (phospho- and glycolipids) from [1-^{14}C] acetate was observed in mature needles from hydroponically grown jack pine seedlings. Treatment of the seedlings with vanadium (V) or nickel (Ni) produced marked concentration-dependent inhibitions in the biosynthesis of all polar lipids. Nickel appeared to be more inhibitory than V at 10 ppm. Fumigation of seedlings with gaseous SO_2 (0.34 ppm) also resulted in reduced biosynthesis of polar lipids. Combined treatment of plant seedlings with metal (V or Ni) and SO_2 produced inhibitory effects that were similar to those produced by metal alone; however, SO_2 did produce an additive inhibitory effect at 10 ppm V.

98. Kingston, D.G.O.; Mahendrappa, M.K.; Salonius, P.O. 1978. Stand and soil changes after fertilization of semimature jack pine in northern New Brunswick. Can. For. Serv. Inf. Rep. M-X-91. (CFS-M)

A fertilization trial was initiated in 1973 in a semimature jack pine (Pinus banksiana Lamb.) stand. The treatments consisted of nitrogen at a rate of 168 kg N ha^{-1} as urea applied alone and in combination with phosphorus at a rate of 168 kg P ha^{-1} as triple superphosphate. Soil and foliar nutrient levels were determined before and after fertilization. Stand responses such as mortality, dbh, and gross increases in total and merchantable volumes were periodically measured.

Concentrations of nitrogen appear to have increased only in L and F horizons due to urea fertilization. Little downward movement of added N seems to have taken place in this jack pine stand. Phosphorus levels, however, increased in both the organic and inorganic horizons in P-treated plots. Addition of N alone and in combination with P increased foliar-nitrogen levels, while P alone did not seem to affect the foliar-N levels. Application of triple superphosphate resulted in higher foliar-P levels in 1973 and 1974, but in 1975 it had declined to control levels. Treatment with N and P did not significantly affect foliar weight in either 1974 or 1975.

Mortality was consistently higher in the control plots and decreased in the order of N1P0 > N1P1 > N0P1. Fertilization with N and NP consistently produced higher percent basal area increase (PBAI) than the control or P treatment. Regardless of the treatment, dominant and codominant trees exhibited highest PBAI. The treatment effects on gross increases in total and merchantable volumes were similar to the effects on PBAI. In three growing seasons, the treatment with 168 kg N ha^{-1} produced about 4 m^3 ha^{-1} of merchantable wood over the control. Application of P with nitrogen yielded an additional volume of 3 m^3 ha^{-1}.

99. LeBlanc, F.; Robitaille, G.; Rao, D.N. 1974. Biological response of lichens and bryophytes to environmental pollution in the Murdochville copper mine area, Quebec. J. Hattori Bot. Lab. 38:405-433. (LFC)

Lichen and bryophytes influenced by the emissions of a copper smelter are mapped using the Index of Atmospheric Purity (IAP). A negative correlation was found between the IAP, the distance from the smelter and the concentration of metal in the lichens and mosses.

100. LeBlanc, F.; Robitaille, G.; Rao, D.N. 1976. Ecophysiological response of lichen transplants to air pollution in the Murdochville Gaspé copper mines area. J. Hattori Bot. Lab. 40:27-40. (LFC)

The "transplantation" method has been used recently to study the effects of air pollution on lichens and bryophytes (Brodo 1961; LeBlanc and Rao 1966; Schonbeck 1969). In this method a lichen and/or bryophyte species, along with its substrate which may be soil, rock or bark, is transferred from a relatively unpolluted area to a polluted one and is allowed to remain there for some definite period of time. The post-exposure changes induced in the transplant are then compared, both qualitatively and quantitatively, with those of the control. These changes, in respect to their magnitude, are then related to the degree of pollution prevailing in the area. A series of such transplants, when located along a gradient of pollution in an otherwise more or less ecologically uniform area, could help delineate a given territory into approximate isotoxic zones.

To study the pollution intensity and its spatial distribution pattern in the Murdochville Gaspé copper mines area, in Northeastern Québec, we transplanted lichen-bearing bark discs onto trees at various sites in the area surrounding the Murdochville copper smelter.

101. L'Hirondelle, S.J.; Addison, P.A. 1985. Effects of SO_2 on leaf conductance, xylem tension, fructose and sulfur levels of jack pine seedlings. Environ. Pollut. (Ser. A) 39:373-386. (NoFC)

Ten-week-old jack pine seedlings were exposed to a series of SO_2 concentrations (0.1 to 1.0 $\mu L\ L^{-1}$) and durations of fumigation (0-96 h) under controlled conditions. Leaf conductance, xylem tension and fructose level decreased and sulfur content increased, as SO_2 concentration and duration increased. Few significant changes were detected before visible injury occurred. Stomatal response was not rapid, and complete closure was found only at high concentrations and long durations. Xylem tension lagged behind leaf conductance in response, but the pattern was similar. Changes in fructose levels were small and gradual. Sulfur content increased significantly with SO_2 exposure after 10 h of fumigation. Multiple regressions, used to describe three-dimensional response surfaces for each variable, all included a crucial interaction term. Although the regressions were highly significant, their predictive power was limited owing to the high natural variability in the seedlings.

102. L'Hirondelle, S.J.; Addison, P.A.; Huebert, D.B. 1985. Growth and physiological responses of aspen and jack pine to intermittent SO_2 fumigation episodes. Can. J. Bot. 64:2421-2427. (NoFC)

Five-week-old aspen seedlings and 8-week-old jack pine seedlings were exposed to a 3-h SO_2 fumigation episode (peak = 0.78 $\mu L\ L^{-1}$, mean = 0.30 $\mu L\ L^{-1}$) 0, 2 or 5 times per week. Intermittent SO_2 fumigation for 7-8 wk had no consistent significant effect on aboveground biomass or prefumigation net assimilation rate (NAR) and leaf resistance (RL) of either species. A significant decrease (up to 47%) in biomass of fumigated jack pine seedlings was found at 6 wk, but at 7 wk the decrease was not significant. There were significant transient effects of SO_2 on NAR and RL of both species. The maximum decrease in aspen NAR was 38% during fumigation and 13% after fumigation. The maximum postfumigation NAR decrease for jack pine was 18%, with a mean of 12% over 6 wk. Aspen RL increased up to 47% during fumigation and 20% after fumigation. Both species showed full recovery from transient SO_2 effects, and a lack of increased sensitivity to fumigation with time. This could explain why physiological and biochemical effects of SO_2 pollution have not been detected near oil sands operations in northern Alberta.

103. Loman, A.A.; Blauel, R.A.; Hocking, D. 1972. Sulfur dioxide and forest vegetation. Can. For. Serv. Inf. Rep. NOR-X-49. (NoFC)

Foliar symptom development resulting from sulfur dioxide fumigations is described. Since foliar sulfur levels fluctuate in healthy leaves, foliar sulfur content is not suitable as a damage index parameter.

The green plant reflects the sum total effects of biotic and abiotic interacting factors of the environment. The green plant itself can therefore function as a monitoring device. Current ground level concentration standards in Alberta allow for 1.0 ppm of atmospheric sulfur dioxide for periods not exceeding one hour, during periods of flaring. This high concentration will be lethal to all Alberta forest species.

104. Lozano, F.C.; Morrison, I.K. 1981. Disruption of hardwood nutrition by sulfur dioxide, nickel and copper air pollution near Sudbury, Canada. J. Environ. Qual. 10:198-204. (GLFC)

Foliage from each of four hardwood species--white birch (Betula papyrifera Marsh.), red oak (Quercus rubra L.), red maple (Acer rubrum L.), and trembling aspen (Populus tremuloides Michx.)--growing on sites severely and moderately damaged by fumes and dustfall and on control sites near Sudbury, Ontario, and soil from beneath the trees were sampled and analyzed for various chemical constituents. Results indicated that on sites damaged by fumes and dustfall, soils were impoverished with respect to organic matter content, exchangeable bases (particularly Ca and Mg), and trace elements (particularly Mn and Zn). Levels of S, Fe, Cu and Ni were also increased. Foliage analysis provided additional support for the proposition that soils contained near toxic to toxic levels of Ni and Cu. If conditions improve, however, with respect to suppression of Ni or Cu supply, tree growth could be limited by the availability of Ca, Mg, or Mn or even of N or P.

105. Lozano, F.C.; Morrison, I.K. 1982. Growth and nutrition of white pine and white spruce seedlings in solutions of various nickel and copper concentrations. J. Environ. Qual. 11:437-441. (GLFC)

As part of an investigation of the ways in which supply is related to growth and foliage concentration, and as part of a larger problem of tree establishment on certain polluted soils, seedlings of white pine (Pinus strobus L.) and white spruce (Picea glauca (Moench) Voss) were grown from seed over a 20-week period in nutrient solutions of various Ni and/or Cu concentrations in growth chambers. In one series, Ni was supplied during the latter part of the test period at 0, 0.01, 0.1, 1, and 10 ppm; in a second, Cu was supplied at 0, 0.01, 1, 10, and 100 ppm; and in a third, Ni and Cu were supplied together in factorial combination at 0, 1, and 10 ppm. At the end of each experiment the seedlings were harvested and growth and chemical composition were determined. In general, substantial reductions in growth occurred when concentrations of Ni and/or Cu in the nutrient solutions were 10 ppm. There was some suggestion that white spruce seedlings were more susceptible than white pine seedlings to elevated Ni levels, with the order being reversed for Cu. Foliage concentrations of Ni and/or Cu increased in relation to their concentrations in the external solutions. No definitive trends were evident in foliage concentrations of other elements except Fe and Zn, both of which decreased: Fe in relation to both Ni and Cu supply, Zn chiefly in relation to Ni supply.

106. Magasi, L.P. 1985. Acid Rain National Early Warning System. Manual on plot establishment and monitoring. For. Insect Dis. Surv., Can. For. Serv., Ottawa, Ont. 51 p. (CFS-HQ, CFS-M)

The methodology for the establishment and monitoring of plots for the national network of forest sites is described. Forms to record observations following the protocol are provided.

107. Magasi, L.P. 1988. Acid Rain National Early Warning System. Manual on plot establishment and monitoring. For. Insect Dis. Surv., Can. For. Serv. Inf. Rep. DPC-X-25. (CFS-HQ, CFS-M)

The revised methodology for the establishment and monitoring of plots for the national network of forest sites is described. Forms to record observations following the protocol are provided.

108. Mahendrappa, M.K. 1972. Non-biological decomposition of nitrite in forest soils. Can. For. Serv. Inf. Rep. M-X-35. 23 p. (CFS-M)

Soil organic matter certainly plays an important role in NO_2^- decomposition. Its effects on the nature of products formed, however, depend on the reaction sites exposed. It appears that contrary to experience in agricultural soils in which the quantity of N_2O produced is dependent on the organic matter content, N_2O formation in forest soils is dependent on the quantities of NO_2^- decomposed. The influence of the organic matter in alluvial and illuvial layers on the quantities of N_2 formed was different. In forest soils, in which temporary accumulation of NO_2^- occurs, loss of N in the form of N_2 is possible. Evolution of oxides of N in the forms of NO and NO_2 is also likely to occur, and their degree and significance need to be understood.

109. Mahendrappa, M.K. 1974. Volatilization of oxides of nitrogen from nitrate-treated black spruce raw humus. Soil Sci. Soc. Am. Proc. 38:522-523. (CFS-M)

Raw humus sods covered with sphagnum (Sphagnum sp.) and feather (Pleurozium sp. and Hypnum sp.) mosses were treated with various forms of nitrate and then incubated in glass tanks with air passing over the sods. Oxides of nitrogen removed from the glass tanks by air were absorbed by two traps containing alkaline permanganate solution.

Volatilization of oxides of nitrogen was observed in all cases. The quantities of oxides of nitrogen evolved decreased with the treatments in the order: $Al(NO_3)_3 > Ca(NO_3)_2 > NH_4NO_3 > KNO_3$. In all the treatments, the proportion of added nitrate-nitrogen trapped as oxides was very small (average of 0.005%). The L and F layers of raw humus became more acid with nitrate treatments.

110. Mahendrappa, M.K. 1978. Changes in the organic layers under a black spruce stand fertilized with urea and triple superphosphate. Can. J. For. Res. 8:237-242. (CFS-M)

Changes in the levels of soil nutrients and decomposition of organic matter under a black spruce (Picea mariana (Mill.) B.S.P.) stand treated with urea and triple super-phosphate were studied over five growing seasons.

The application of both N and P increased organic matter decomposition as indicated by decreases in the weights of L and F layers in fertilized plots and by the calculated values for the decomposition rate factors. Added urea moved down through the organic horizon and changed both physical and chemical characteristics of the organic material, particularly the F and H layers, which became greasy to touch as compared with those in the untreated plots. The thickness of the organic horizons was decreased in most of the urea-treated plots. Treatment effects on the levels of exchangeable ammonium N were detectable at the end of five growing seasons. Differences in the levels of ammonial N were greater in the L layers at the end of first growing season (1968) and in the F and H layers after 5 years (1972). The concentration of available P, however, showed treatment effects in 1968 but not in 1972. Addition of P with urea retarded the movement of N.

111. Mahendrappa, M.K. 1979. Interception of aerially applied ammonium nitrate by hardwood and softwood trees. Can. J. For. Res. 9:437-441. (CFS-M)

The quantities of ammonium and nitrate nitrogen (N) in stemflow and throughfall samples collected from hardwood and softwood stands were determined before and after aerial application of ammonium nitrate. Distribution of fertilizer reaching the ground during the aerial fertilization of the area was determined daily during the operation.

Before fertilization, the concentrations of nitrate and ammonium N in stemflow and throughfall samples from both hardwood and softwood stands were negligible. Although more fertilizer prills per unit area were recovered in the hardwood than in the softwood stands, N levels in the stemflow and throughfall samples collected were higher in the softwood than in the hardwood stands. It was, therefore, concluded that the softwood trees intercepted larger quantities of aerially applied ammonium nitrate than did the hardwood trees.

112. Mahendrappa, M.K. 1980. Relationships between different estimates of mineralizable N in the organic materials under black spruce stands. Can. J. For. Res. 10:517-522. (CFS-M)

Samples of top (L) and middle (F) organic horizons from beneath a black spruce (Picea mariana (Mill.) B.S.P.) stand were treated with urea and diammonium phosphate (DAP) prior to incubation in the forest and in controlled environment chambers. KCl-extractable NH_4^+N, KCl-extractable Kjeldahl N and alkaline-distillable N in autoclaved portions of the samples (ADNAS) were determined before and after incubation. Samples of L, F, and H (bottom) horizons collected periodically from the fertilizer-treated plots in a black spruce stand were subjected to similar analyses.

A linear relationship was found between the quantities of KCl-extractable NH_4^+N and ADNAS in samples incubated under different conditions. Factors such as temperature regime, fertilizer additions, and position of the organic horizons in the soil did not influence the relationship. The observed relationship was valid for the field samples from a fertilized black spruce stand and it appears logical to suggest that the estimate of ADNAS should be considered a good indicator of net mineralizable hence potentially available N. Estimates of ADNAS appear to be preferable to KCl-extractable NH_4^+N because of the rapidity and simplicity of the analysis involved.

113. Mahendrappa, M.K. 1982a. Effects of SO_2 pollution on nitrogen transformation in some organic soils of northeastern New Brunswick: ammonia volatilization. Can. J. For. Res. 12:458-462. (CFS-M)

Ammonia volatilization from organic (raw humus) horizons collected from an area in northern New Brunswick variously affected by SO_2 (point source) pollution was studied under laboratory conditions. Samples were treated with urea at the rates of 0, 15, and 30 mg N per jar (0, 150, and 300 kg N ha^{-1}) and incubated in closed dynamic systems for 14 days.

The quantity of ammonia volatilized was proportional to the rate of urea application. While the quantities of ammonia given off from samples representing unaffected and moderately affected areas did not differ significantly, they were more than 20 times larger than the quantities volatilized from samples representing severely affected areas. The effect of SO_2 pollution on ammonia volatilization was related to the original pH of the organic horizons before incubation. The reduced pH of the soil, owing to SO_2 pollution, appeared to affect ammonia volatilization through the inhibitory effect of increased hydrogen ion concentration, and (or) by the ability of the acidic upper soil horizons to trap NH_3 released in the lower horizons. The threshold pH at which ammonia volatilization is drastically reduced lies between 3.5 and 4.0.

114. Mahendrappa, M.K. 1982b. Effects of forest cover type and organic horizons on potential water yield. Pages 215-224 in Can. Hydrol. Symp. '82, 14-18 June, Fredericton, N.B. (CFS-M)

Distribution of rainfall in open areas and measured as stemflow and throughfall in six softwood and three hardwood stands was characterized using several years' data. All the stands are located within a radius of about 5 km from the headquarters of the Acadia Forest Experiment Station, in central New Brunswick. Through extensive sampling of organic and inorganic horizons under these stands the weights, thickness, and moisture contents of individual horizons were also determined.

The results show that the proportion of rainfall reaching the ground as stemflow is very small (1-6%). The proportion of throughfall ranges greatly depending on the intensity of rainfall. However, over a wide range of rainfall amounts throughfall showed a strong linear relationship with open rain quantities. Using such linear relationships the effects of forest cover on the quantities of rain reaching the ground were statistically evaluated.

Evaluation of the data on soils shows that distinct differences exist between the weights and thickness of organic horizons under different stands. Calculations based on the weights and moisture retention characteristics of these horizons suggest that forest cover is not the only determining factor affecting potential water yield. The combined effects of forest cover and the associated organic horizons on potential water yield are more pronounced when the rainfall is less than 10 mm per event.

115. Mahendrappa, M.K. 1983a. Chemical characteristics of precipitation and hydrogen input in throughfall and stemflow under some eastern Canadian forest stands. Can. J. For. Res. 13:948-955. (CFS-M)

At the Acadia Forest Experiment Station (AFES) in central New Brunswick chemical characteristics of rain samples collected at five different locations were determined during the 1977-1981 period. Throughfall and stemflow samples from six softwood and three hardwood stands were collected and chemically characterized starting from the early 70's. In 1976 two of four plots in each of the stands were treated with urea at a rate of 225 kg N ha^{-1}. Both the quantities of rain and their pH values varied considerably between collections, months, and years. The weighted mean pH of summer (May-October) rain collected intensively during the 1977-1981 period ranged from 4.5 to 5.1, with an overall weighted average value of 4.75 for the 5 years. Sulfur and nitrate N measured during May-October 1982 amounted to 6.18 and 1.52 kg ha^{-1}, respectively, for the 6-month period. The concentration of hydrogen ion in the throughfall was less than that in the rain. Hardwood throughfall had lower hydrogen levels (higher pH) than the softwood throughfall. The pH of the stemflow from softwoods was lower than that of rain in most cases. Although not significantly, the hydrogen ion concentration of both throughfall and stemflow on the fertilized plots was lower than on the untreated plots. The hydrogen load of rain was reduced by all tree species, but there was considerable variation between species in their abilities to decrease total hydrogen reaching the soil.

116. Mahendrappa, M.K. 1985. Precipitation chemistry affected by differences in location of collection sites and storage methods. Atmos. Environ. 19:1681-1684. (CFS-M)

An investigation was carried out to evaluate rigorously the possible differences in measured concentrations of hydrogen, nitrate and sulfate ions in "bulk" precipitation samples that may be caused by variations in location of rain collectors and duration and temperature of storage. Storage of precipitation samples, up to one month, both in the coldroom and in the field resulted in a significant reduction in the concentration of hydrogen ions. Only field storage caused a statistically significant reduction in the concentration of nitrate in the precipitation samples. Levels of sulfate ions were not found to be significantly affected by storage either in the field or in coldrooms. Samples collected from a rain gauge located on a building roof were more acidic than those collected in open spaces in forests. Though all samples showed similar seasonal patterns in the concentrations of sulfate and nitrate, the individual values consistently differed from each other. The results suggest a definite need to locate national monitoring stations away from point source (including home heating system) pollution.

117. Mahendrappa, M.K. 1986. Abilities of organic horizons under some eastern Canadian forest stands to alter the acidity of rainwater. Can. J. For. Res. 16:18-22. (CFS-M)

Various precipitation data, collected over a 13-year period from different softwood and hardwood stands located at the Acadia Forest Experiment Station (AFES) in central New Brunswick, are evaluated to demonstrate differences between stands in their ability to alter the acidity of rainwater. In the soil organic horizons, retention and exchange processes are shown to be effective in altering the acidity of rainwater.

Significant species effects in the quantities of water retained by the organic horizons are recognizable owing to differences in the quantities of organic materials accumulated under each stand and their moisture-retention characteristics. In turn, differences in the quantities of liquid retained in the organic horizons affect the residence time of the acid components of rain reaching the mineral soil. Major differences in chemical characteristics such as cation-exchange capacity, percent base saturation, and pH of the organic horizons suggest that the interactions of acid components of wet and dry deposition of air pollutants can be significantly different depending upon the species composition of stands.

118. Mahendrappa, M.K. 1987. Tree species and urea treatment effects on sulfur and metals in throughfall and stemflow of some eastern Canadian forest stands. Can. J. For. Res. 17: 1035-1042. (CFS-M)

Concentrations and quantities of S, Al, B, Cu, Fe, Mn, Ni, Pb, and Zn were determined in throughfall (TF) and stemflow (SF) samples, collected from 1971 to 1981, in six softwood and three hardwood stands located at the Acadia Forest Experiment Station (AFES) in central New Brunswick, Canada. Incident bulk precipitation samples collected during the same period in open areas near each of the stands were also analyzed for the above elements. Analyses were carried out using the freeze-dried total solids in samples of TF, SF, and rainwater.

119. Mahendrappa, M.K. 1988. Acid rain effects on nitrogen availability from litter and organic matter decomposition in P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (CFS-M)

Here an attempt is made to review the existing literature on the effects of acid rain on nitrogen availability as influenced by litter and organic matter decomposition. This presentation consists of a discussion of sequential processes of nitrogen transformations starting with nitrogen input to the ecosystems via dry and wet deposition, fixation, leaching of litter materials, breakdown of litter and organic materials, and potential availability of nitrogen to forest trees during various phases of litter and organic matter decomposition. The role of microfauna and microflora on the decomposition processes as influenced by acidification of the ecosystem is also discussed. Finally, some data gathered by us concerning acid rain effects on N transformation processes and the role of other factors on these processes are presented.

120. Mahendrappa, M.K.; Foster, N.W.; Weetman, G.F.; Krause, H.H. 1986. Nutrient cycling and availability in forest soils. Can. J. Soil Sci. 66:547-572. (CFS-M, GLFC)

Nutrient availability in different forest soils must be known before increased wood production can be sustained either by adding supplemental nutrients or by judicious silvicultural operations to optimize the linkage between the variable nutrient requirements of forest crops. This is complicated by the variable availability of nutrients on forest sites during crop development. Forest crops unlike agricultural crops have long rotation periods which make it difficult to apply agricultural methods of estimating potentially available nutrients directly to forest soils. Presented in this review are (i) various approaches used in forestry to estimate the nutrient supplying potential of different sites, (ii) factors affecting nutrient availability, and (iii) evidence to suggest that nutrient cycling processes in forest ecosystems are important factors affecting tree growth. It is suggested that data from chemical analyses of soil samples collected at specific times and sites should be used with caution for both practical decision making and simulation modelling purposes.

121. Mahendrappa, M.K.; Kingston, D.G.O. 1982. Prediction of throughfall quantities under different forest stands. Can. J. For. Res. 12:474-481. (CFS-M)

The quantitative distribution of throughfall in fertilizer-treated and control plots under six softwood and three hardwood stands and rainfall in open areas close to these stands were intensively measured during 1977-1978. Standard rain gauges and improvised funnel-type collectors were used for measuring both throughfall and rainfall in the open. The improvised funnel-type collectors with an orifice smaller than that of the standard rain gauges were found to be suitable for accurately measuring quantities of both open rainfall and throughfall. Simple linear regression models of the form $Y = bX - a$ were sufficient to predict throughfall quantities (Y) based on rainfall (X) measurements. The relationship between the quantities of throughfall and rainfall was highly significant in each case. Application of urea at a rate of 225 kg N ha^{-1} did not affect either the slope (b) or the elevation (a) of the relationship. No significant differences were found between the relationships calculated for 1977 and 1978 for any species except balsam fir (Abies balsamea (L.) Mill.) and larch (Larix laricina (Du Roi) K. Koch). The difference for balsam fir was probably a result of extensive defoliation by the spruce budworm (Choristoneura fumiferana (Clem.)). In most cases, values of the slopes (b) of the models for the different species were not significantly different. The nine species did, however, differ significantly from one another in terms of the minimum quantity of rain (a/b) that must fall before throughfall was measurable in the collectors.

122. Mahendrappa, M.K.; Salonius, P.O. 1982. Nutrient dynamics and growth response in a fertilized black spruce stand. Soil Sci. Soc. Am. J. 46:127-133. (CFS-M)

In 1968, a forest fertilization experiment was established in a black spruce (Picea mariana Mill. B.S.P.) stand in central New Brunswick. A factorial combination of three levels of nitrogen (N) in the form of urea and three levels of phosphorus (P) in the form of triple superphosphate was applied to duplicate circular plots. During the 10 years after fertilizer application, various components of the nitrogen cycle, organic matter transformations, and microbial activity were monitored in both field and laboratory using soil samples from the black spruce stand under study. Concurrent stand responses to fertilizer applications were also determined periodically. Application of nitrogen and phosphorus fertilizers increased the foliar N levels in all treated plots. Nitrogen levels in litterfall materials showed similar increases. Concentrations of nitrogen in litter needles from treated and control plots, respectively, averaged 79 and 66% of those in the crown. The rate of respiration in the organic raw humus materials was higher when incubated with green litter needles from treated plots than when incubated with similar litter from control plots. The stimulatory effect of the litter needles seems to be related to an interaction between dry summers and fertilizer treatments. Nitrate was detected in the soil solution collected from N- and P-treated plots. The data suggest a negligible loss of nitrogen due to leaching of nitrate. Growth rates of trees after fertilizer treatment are related to foliar nutrient levels and to growth rates of trees prior to fertilization.

123. Malhotra, S.S. 1976. Effects of sulfur dioxide on biochemical activity and ultrastructural organization of pine needle chloroplasts. New Phytol. 76:239-245. (NoFC)

The effects of aqueous SO_2 on the ultrastructural organization of pine chloroplasts and on their photosynthetic activity were determined under laboratory conditions. At aqueous concentrations of 100 and 500 $\mu L\ L^{-1}$, SO_2 caused swelling of thylakoid discs and disintegrated other intrachloroplast membranes, resulting in the formation of small vesicles. This damage was greater in older tissue than in that of younger needles. The biochemical observations such as the Hill reaction activity made on chloroplasts isolated from SO_2-treated pine needles were in good agreement with the cytological observations.

124. Malhotra, S.S. 1977. Effects of aqueous sulfur dioxide on chlorophyll destruction in _Pinus_ _contorta_. New Phytol. 78:101-109. (NoFC)

The effects of aqueous SO_2 on chlorophyll breakdown in lodgepole pine were determined under laboratory conditions. Aqueous SO_2 concentrations ranging from 100 to 500 ppm resulted in a sharp decrease in total chlorophyll content. Chlorophyll a was more sensitive to SO_2 than chlorophyll b. Quantitative determinations of various pigments suggested that SO_2 causes conversion of chlorophyll a into phaeophytin a and chlorophyll b into chlorophyllide b. The suggested conversion of chlorophyll into chlorophyllide induced by SO_2 was supported by increased activity of pine needle chlorophyllase at low aqueous SO_2 concentrations. In addition, there was a decrease in the capability for the pine needles to fix $H^{14}CO_3$. The effect of SO_2 on pigment breakdown and rate of photosynthesis was attributed to the direct action of SO_2 and not to increased acidity.

125. Malhotra, S.S. 1979. Interim report on physiology and mechanisms of air-borne pollutant injury to vegetation 1975-1978. Alberta Oil Sands Environ. Res. Program Rep. No. 45, Alberta Environ. 35 p. (NoFC)

Biochemical studies conducted under controlled conditions suggested that low concentrations of SO_2 which normally do not produce any visible symptoms on the foliage cause injury to forest vegetation by altering pigment (chlorophyll, phaeophytin and chloropyllide) metabolism, by inhibiting lipid synthesis and activities of various important enzyme systems and by causing ultrastructural disorganization of cellular membranes.

In general, aqueous and gaseous SO_2 produced results very similar to each other. Plants, when fumigated with SO_2 at the ambient air quality standards, exhibited various biochemical responses that can have deleterious effect on the normal growth and yield of vegetation. However, 24-48 h after transferring the fumigated plants to an SO_2-free environment, there was a considerable recovery of such functions.

The results obtained so far clearly indicated that chlorophyll/phaeophytin ratio, Mg^{2+} content, lipid biosynthesis and acid phosphatase and malate dehydrogenase activities of plant foliage are very sensitive indicators of SO_2 concentrations. Using such techniques, an attempt was made to detect pre-visual SO_2 injury to jack pine and white spruce from the field impingement area (immediate vicinity of GCOS plant). Although a gradient in sulfur content of the collected material was evident, there was no appreciable difference in any of the biochemical and physiological functions that responded to SO_2 under laboratory conditions. However, more experimentation needs to be conducted with some of the sensitive species of vegetation to determine air pollution effects on forest vegetation.

126. Malhotra, S.S.; Addison, P.A. 1979. Interim report on symptomatology and threshold levels of air pollutant injury to vegetation, 1975-78. Alberta Oil Sands Environ. Res. Program Rep. No. 44, Alberta Environ. 13 p. (NoFC)

Six boreal forest plant species were fumigated in a newly developed environmental growth chamber with SO_2 control capability, for up to 40 days at 0.34 ppm SO_2. All species showed a gradual decline in CO_2 gas exchange which was related to symptom development characteristic of SO_2 toxicity. Paper birch was the most sensitive species to SO_2 injury followed by green alder, jack pine, labrador tea, and white and black spruce.

127. Malhotra, S.S.; Addison, P.A.; Khan, A.A. 1980. Symptomatology and threshold levels of air pollutant injury to vegetation, 1979-80. Alberta Oil Sands Environ. Res. Program Rep. No. 109, Alberta Environ. 17 p. (NoFC)

A number of coniferous and deciduous species that had been growing on the Suncor tailings dike for five to seven years were fumigated with 0.34 ppm SO_2 under controlled environmental conditions. The results obtained were compared with those from similar fumigations of the same species grown in "uncontaminated" native soils. The coniferous species (*Pinus banksiana*, *Picea glauca*, and *Picea mariana*) grown in tailings sand were much more sensitive to SO_2 injury than those grown in native soils (Dystric Brunisol). They required approximately half as much fumigation time to exhibit physiological and visual injury even though they were collected less than 30 km apart. The woody angiosperms (*Populus tremuloides*, *Caragana arborescens*, and *Salix* sp.) were not ranked due to a pollution chamber breakdown during the experiment. No additional plant material was available to repeat this experiment.

128. Malhotra, S.S.; Blauel, R.A. 1977. Effects of sulfur dioxide on the forest ecosystem. *In* The oil sands of Canada-Venezuela, 1977 Symposium. Can. Inst. Min. Metall., Edmonton, Alta. (NoFC)

This is a review of the literature which includes an overview of the impact of sulfur dioxide on the ecosystem, the effect of SO_2 on the growth of forest vegetation, effect of SO_2 on chlorophyll content, ultrastructure and biochemical functions, as well as impact assessment and ecological bench-marking and biomonitoring of soil and vegetation. These latter two areas are presented in terms of a methodology and considerations when carrying out such studies.

129. Malhotra, S.S.; Blauel, R.A. 1980. Diagnosis of air pollutant and natural stress symptoms on forest vegetation in western Canada. Can. For. Serv. Inf. Rep. NOR-X-228. (NoFC)

Industrial operations in Alberta, Saskatchewan, Manitoba and the Northwest Territories release airborne emissions that can injure surrounding forest vegetation. This report describes symptoms of these pollutants and of natural stresses that may appear similar. The industries discussed include natural gas processing plants, oil wells and refineries, oil sands plants, metal mines and smelters, cement plants, potash industry, pulp and paper mills, and agricultural chemical production and application. Nineteen pages of color photographs provide examples of these symptoms on forest vegetation.

130. Malhotra, S.S.; Hocking, D. 1976. Biochemical and cytological effects of sulfur dioxide on plant metabolism. New Phytol. 76:227-237. (NoFC)

Biochemical effects of sulfur dioxide arise from its unique ability to act as an oxidizing or a reducing agent. Among some of the important metabolic effects are direct interference with photosynthetic CO_2 fixation (competitive inhibition of ribulose diphosphate carboxylase by $SO_3^{=}$) and with energy metabolism (inhibition of mitochondrial ATP production by $SO_3^{=}$). Many indirect effects result from formation of sulfites and organic sulfonates with other cell constituents. These compounds can cause inhibition of a variety of metabolic enzyme systems. All these factors are probably instrumental in the gross disruption of chloroplasts and mitochondrial ultrastructure. Injurious effects result when sulfur dioxide is taken up in excess of the capability of the tissue to incorporate sulfur into the normal metabolic activities. The ubiquitous presence of small amounts of SO_2 and the subtle and varied nature of its biochemical effects suggest that crop losses to SO_2 pollution may be more widespread and serious than is generally suspected.

131. Malhotra, S.S.; Khan, A.A. 1978. Effects of sulfur dioxide fumigation on lipid biosynthesis in pine needles. Phytochemistry 17:241-244. (NoFC)

Pine needle tissues were shown to incorporate acetate [1-^{14}C] into phospho-, galacto- and neutral lipids. The major incorporation of the label among these lipids was always in the phosphatidyl choline (PC) fraction. The amount of label among the other lipid fractions varied depending on the age and source of the needle tissues (lodgepole or jack pine). In general, the biosynthesis of these lipids was more efficient in the developing than in the fully developed tissue. Treatment of the needle tissue with either gaseous or aqueous SO_2 markedly inhibited lipid biosynthesis. These effects were more pronounced in developing than in mature tissue. Fumigation with gaseous SO_2 showed that both concentration and duration of exposure affected the extent of lipid biosynthetic inhibition. Lipid biosynthetic capacity partially or completely recovered when plants were removed from the SO_2 environment. Plants exposed to moderate SO_2 concentrations (0.18-0.20 $\mu L\ L^{-1}$) for a period of 24 h recovered faster than those exposed to near lethal SO_2 concentrations (0.34-0.37 $\mu L\ L^{-1}$) for only 1 h.

132. Malhotra, S.S.; Khan, A.A. 1980a. Physiology and mechanisms of air-borne pollutant injury to vegetation 1979-80. Alberta Oil Sands Environ. Res. Program Rep. No. 110, Alberta Environ. 44 p. (NoFC)

Several important biochemical functions in an epiphytic lichen, *Evernia mesomorpha*, in response to controlled SO_2 exposures were studied. Appreciable changes in these functions were observed even at a very low SO_2 concentration (0.1 ppm), suggesting that epiphytic lichens are probably one of the most sensitive species to SO_2 exposures. Fumigation of these lichens at 0.34 ppm SO_2 for 3 to 7 d caused irreversible injury to nearly all the biochemical functions studied.

Controlled fumigation of vascular species with low levels of SO_2 and NO_2 caused appreciable changes in several biochemical and physiological functions; in many cases such exposures did not produce any visual symptoms of pollutant toxicity. Biochemical indicators such as peroxidase and glycollate oxidase exhibited a synergistic response and ribulose diphosphate carboxylase an additive response to a SO_2-NO_2 mixture in alder. These enzymes, when examined from the pine and birch, produced little or no additional response to the mixture compared to that produced by either pollutant individually.

Metal pollutants such as vanadium and nickel were very toxic to various cellular processes. The maximum biochemical response was obtained by the metals alone followed by SO_2. The pollutant mixture (metal + SO_2) did not produce much more additional response than that caused by metals alone.

Biochemical and physiological methods developed in the laboratory were utilized for detecting previsual air pollutant injury to jack pine and highly sensitive epiphytic lichens in the oil sands area. The biochemical functions examined showed no significant differences between sites at different distances from the pollutant source. The lack of response is considered to be due to the ability of vegetation to recover its metabolic functions between the rare incidents of heavy fumigation. It is possible that the minor pollution effects, if any, may be masked by the natural variability between sites.

133. Malhotra, S.S.; Khan, A.A. 1980b. Effects of sulfur dioxide and other air pollutants on acid phosphatase activity in pine seedlings. Biochem. Physiol. Pflanzen 175:228-236. (NoFC)

Acid phosphatase (EC 3.1.3.2) activity in 6-month-old needles of jack pine (Pinus banksiana) seedlings was much higher than in 3-month-old needles. The soluble and loosely bound (salt-extractable) enzymes produced the same electrophoretic pattern, which suggests that the enzymes are very similar in nature. Treatment of pine seedlings with SO_2 inhibited acid phosphatase activity. After exposure of the seedling to 0.35 $\mu L\ L^{-1}$ SO_2 for 24 h, the inhibition was more pronounced in the older (3-mon) than in the younger (1-mon) tissues from the same seedlings. Upon removal of plants from the SO_2 environment, the inhibitory effects of SO_2 were completely reversed in plants exposed for short durations (1 h) but were unchanged in the plants exposed for long durations (24 h). Among the other pollutants tested, fluoride, zinc, arsenate, aluminum and copper considerably inhibited enzyme activity.

134. Malhotra, S.S.; Khan, A.A. 1981. Effects of SO_2 and heavy metals on Pinus banksiana. Proc. XI IUFRO World Congr. 137:299-307. (NoFC)

Exposure of pine seedlings to solutions of heavy metals (vanadium and nickel) either singly or in combination with SO_2 resulted in the uptake of metal, biochemical disturbances and production of severe visual injury symptoms. Individual metal pollutants such as vanadium and nickel and SO_2 proved to be highly toxic to various metabolic processes (glyco- and phospholipids biosynthesis, activities of ribulose diphosphate carboxylase, peroxidase, glycollate oxidase and acid phosphatase). In general, the pollutant mixtures (metal + SO_2) did not produce much more additional response than that caused by metals alone. The response of various biochemical functions to each pollutant appeared to be related to the pollutant uptake by treated tissues.

135. Malhotra, S.S.; Khan, A.A. 1983. Sensitivity to SO_2 of various metabolic processes in an epiphytic lichen Evernia mesomorpha. Phytochemistry 178:121-130. (NoFC)

In the epiphytic lichen Evernia mesomorpha Nyl., metabolic processes such as photosynthetic CO_2 fixation and protein and lipid biosynthesis were found to be very sensitive to SO_2. Exposure of the lichens to 0.1 ppm of gaseous SO_2 for increasing durations produced a progressive reduction in these processes. Protein biosynthesis appeared to be the most sensitive to SO_2. Fumigation of lichen tissues at 0.34 ppm of SO_2 for increasing durations caused an increased phytotoxic effect on all three metabolic processes. Such fumigations also inhibited acid phosphatase activity and caused an increase in the sulfur content of the tissues. During an SO_2-free period after fumigation, all processes recovered partially or fully in lichens exposed to 0.1 ppm SO_2 but showed little or no recovery in lichens exposed to 0.34 ppm SO_2.

136. Malhotra, S.S.; Khan, A.A. 1984. Biochemical and physiological impact of major pollutants. Pages 113-157 in M. Treshow, ed. Air pollution and plant life. John Wiley & Sons Ltd., New York, NY. (NoFC)

Most plants evolve in a predominantly gaseous environment. When composition of this environment exceeds the critical limits of adaptation and tolerance, stress is imposed and the most sensitive components of the system begin to malfunction. Any gas can cause such a stress when a threshold concentration is reached. Regardless of the air pollutant, the impact invariably involves interactions with one or more biochemical metabolic processes. First exposed are the stomata and their guard cells, which may respond first if they are sufficiently sensitive. The gas then passes into the intercellular spaces to become dissolved on the moist internal surfaces, characteristically contacting and influencing membranes and the cellular pH. Penetrating the cytoplasmic membrane, a pollutant is relatively free to attack the organelles within and the substances throughout. A pollutant may react with a number of metabolites along its course of migration through the cell. Consequently, numerous reaction sites may be, and often are, involved.

The reactions affected depend on the properties and chemical form of the pollutant and certain sites and reactions seem especially prone to disruption: these include membranes whose permeability may be altered; photosynthetic reactions, e.g. photophosphorylation and carboxylation; electron transport and respiration. Metabolic pools are affected: carbohydrates, organic acids and amino acids, proteins and lipids are all involved, but the specifics vary with the pollutant.

137. Malhotra, S.S.; Sarkar, S.K. 1979. Effects of sulfur dioxide on sugar and free amino acid content of pine seedlings. Physiol. Plant. 47:223-228. (NoFC)

Treatment of jack pine (Pinus banksiana Lamb.) seedlings with gaseous SO_2 resulted in a shift between the reducing and non-reducing sugars. Increasing concentrations of gaseous SO_2 caused an increase in reducing sugars and a decline in the non-reducing sugars, suggesting a conversion from the latter to the former at high SO_2 concentrations. The total amino acid content of the intact tissues also increased with increasing concentrations of gaseous SO_2. Gas-liquid chromatographic analyses of the amino acids indicated that SO_2 (2.34 mg m^{-3} for 96 h) resulted in an increase in the content of tyrosine, lysine, and arginine, and a decrease in the content of serine and glutamic acid. The enzymatic and other implications of such changes are discussed.

138. Martel, J.P. 1983. Physical and hydrological characteristics and water balance of organic matter in a Laurentian fir stand at Laflamme Lake in the Montmorency Forest. (Available only in French.) Masters thesis, Laval Univ., Quebec City, Que. Contract to LFC/CFS. 88 p. (LFC)

The organic matter layer of a Laurentian fir stand in the Montmorency Forest, located 80 kilometres north of Quebec City, was studied in terms of its physical and hydrological characteristics (Chapter I), and hydrological balance (Chapter II).

The objective of the first part was to assess the thickness, weight, density and various water capacities of the organic layer and to determine whether these characteristics varied at the experimental site.

Total organic matter and organic matter of each horizon in the entire Lake Laflamme watershed were sampled. The average thickness, bulk density (dry) and dry weight were found to be 7.8 cm, 0.108 g/cm^3 and 81.8 tonnes/ha respectively. These characteristics did not vary significantly within the watershed.

Using theoretical calculations and field and laboratory experiments, the water retentivity profile was plotted and the field capacities, theoretical saturation, theoretical retention, maximum storage and minimum and maximum water content were estimated at 2.08, 7.18, 5.09, 2.61, 0.61, and 3.22 cm respectively. The results were compared with those from other coniferous stands.

The purpose of the second part was to compare water contents measured at the site with those obtained using Van Wagner's model, and to modify the model as required to adapt it to the conditions at the experimental site.

Water contents of organic matter were measured over three summers, by means of resistor blocks placed at three sample plots. The values were compared with those obtained by the

Van Wagner model used to calculate the fire weather index. The author adapted this model to the conditions of the Lake Laflamme watershed, to enable estimation of the water content of organic matter using standard meteorological parameters such as precipitation, relative humidity and air temperature. On the whole, the modified model provided a good estimate of water contents measured in the field.

139. Maynard, D.G.; Addison, P.A. 1985. Extraction and colorimetric determination of elemental sulfur in organic horizons of forest soils. Can. J. Soil Sci. 65:811-813. (NoFC)

A method is proposed for determining elemental S in organic horizons of forest soils. Elemental S is extracted from the soil with acetone and assayed by a colorimetric method. The procedure is a modification of several existing methods and allows for the extraction of all forms of elemental S. It also reduces the interference of colored extracts from forest litter. The detection limit is 100 mg kg^{-1} (1 mg S° mL^{-1} of solution) and concentrations in excess of 50 000 mg kg^{-1} have been measured. The recovery of S° is approximately 90%. The method is suitable for determining S° in organic forest soils with a wide range of S° concentrations and where a high degree of accuracy and precision is not required. It is rapid, and suitable for routine analysis in laboratories without specialized equipment.

140. Maynard, D.G.; Addison, P.A. 1986. Variability in forest systems as it relates to elemental sulphur effects. Pages 255-285 in Proc. 2nd Symp./Workshop on Acid Forming Emissions in Alberta and their Ecological Effects. Res. Manage. Div., Alberta Environ., Edmonton, Alta. 354 p. (NoFC)

A five-year project was initiated in 1981 to study the effects of sour gas processing on the forest ecosystem in west-central Alberta. A biomonitoring network was established in a 30 X 30 km area surrounding the Strachan and Ram River sour gas plants. In addition, detailed studies were initiated to determine the mechanisms and magnitude of the particulate S° impact on the soils and vegetation of the area. This paper reports on some of the results of this study and the quantification of variability associated with these ecological measurements and its influence on biomonitoring.

A technique was developed to determine elemental S (S°) in soils and to estimate S° deposition. Deposition at sites adjacent to the gas plant was found to be considerably less than the deposition that must have occurred previously to produce the S° concentrations present in the surface organic horizon (LFH). Significant changes in soil chemical properties and plant cover were observed at these sites impinged with heavy concentrations of S°. However, changes at sites with low concentrations of S° (<5000 mg kg^{-1}) were more difficult to assess.

Random or natural soil variability ranged from 24 to 102% on a regional basis. Spatial variability was the largest component of the partitioned variability; however, there was a significant regional component as well. For the soil parameters measured, temporal variability was generally not significant. Because of the high variability, concentration differences in the order of 50% or greater were needed to be considered significant. Plant cover estimates measurement errors were high (20%) and changes in plant cover between sampling times would have to exceed 20% before interpretation would be possible. Growth measurements were equally as variable.

141. Maynard, D.G.; Addison, P.A.; Kennedy, K.A. 1983a. Elemental sulfur dust deposition on soils and vegetation of lodgepole pine stands in west-central Alberta. In R.W. Wein, R.R. Riewe, and I.R. Methven, eds. Resources and dynamics of the Boreal Zone. Proc. of a conference held at Thunder Bay by Canadian Universities for Northern Studies. (NoFC)

The influence of the addition of elemental sulfur dust on forest vegetation and soils in west-central Alberta was studied using four sites from a larger study on biomonitoring of sulfur effects. The two sites close to the sulfur dust sources (<200 m) had significantly higher total and water-soluble soil sulfur contents in all horizons to a depth of 20 cm. Associated soil changes included both the lowering of pH and a reduction in the total concentration of Mg, K and Mn in the LFH horizon. The effect of the S deposition on the vegetation was the almost complete elimination of the mosses and a reduction in the herb cover. Research is continuing on the controlling factors in the oxidation of elemental S in the soil, the effects of the S dust on soil processes such as nutrient leaching, and the response of vegetation to the changes in soil chemistry.

142. Maynard, D.G.; Addison, P.A.; Kennedy, K.A. 1983b. Impact of elemental sulfur dust deposition on soils and vegetation of *Pinus contorta* stands in west-central Alberta, Canada. Aquillo Ser. Bot. 19:314-325. (NoFC)

The influence of the addition of elemental sulfur on forest vegetation and soils in west-central Alberta was studied using 4 sites from a larger study on biomonitoring of sulfur effects. The two sites close to the sulfur dust sources (<200 m) have significantly higher total and water-soluble soil sulfur contents in all horizons to a depth of 20 cm. Associated changes included both lowering of pH and the loss of Mg and Mn from the LFH horizon. The vegetation had apparently responded to pH change and there was a distinct reduction in both cover and composition of the plant community. The large number of sulfur blocks in Alberta (>100) and the magnitude of the ecological response make this an important future research area.

143. Maynard, D.G.; Germida, J.J.; Addison, P.A. 1985. The effects of elemental sulfur on certain chemical and biological properties of surface organic horizons of a forest soil. Can. J. For. Res. 16:1050-1054. (NoFC)

Elemental sulfur is a by-product of sour natural gas processing in Alberta, Canada. Breakup and weathering of the storage S° blocks have resulted in the deposition of large amounts of S° into adjacent forest ecosystems. This has caused considerable damage to the understory vegetation. Selected chemical and biological properties in surface organic horizons (LFH) that have been exposed to S° for several years were examined over a two-year period. Increasing concentrations of S° and 0.1 M NH_4Cl-extractable S and decreasing pH occurred in the LFH with increasing proximity (750, 250 and 50 m) to the S° source. Thiobacillus thiooxidans appeared to be the main organism responsible for S° oxidation in all LFH samples. The site immediately adjacent to the S° block (50 m) showed reduced concentrations of total and 1.0 M NH_4Cl-extractable Ca, Mg, K, Mn, and P. In addition, in the second year of sampling, CO_2 respiration in non-amended and glucose-amended samples was significantly reduced. The other sites showed no significant decrease in nutrient status or microbial activity. At present, no adverse effects on tree growth have been observed. Our results indicate, however, that a reduction in forest productivity could occur as a consequence of the S° oxidation adversely affecting pH, nutrient status and biological activities of the LFH horizon.

144. Maynard, D.G.; Kalra, Y.P.; Radford, F.G. 1987. Extraction and determination of sulfur in organic horizons of forest soils. Soil Sci. Soc. Am. J. 51:801-806. (NoFC)

There is very little information on the accuracy, precision and make-up of extractable sulfur in surface organic forest soils (LFH). Seven extractants were evaluated for the extraction and determination of sulfate (SO_4-S) and total extractable S on five LFH horizons. The analyses for SO_4-S and total extractable S were carried out by ion chromatography (IC) and inductively coupled argon plasma spectrometry (ICP-AES), respectively. All weak salt extractants removed similar amounts of SO_4-S and total extractable S. The 0.01 M NH_4Cl extractant, however, was found to be the least variable and the most consistent extractant. The precision ranged from 1.9 to 8.4% for the ICP-AES analyses and from 3.7 to 8.9% for the IC analysis excluding the aspen LFH. Quantitative recoveries from 102 to 108% and from 97 to 108% were obtained in the 0.01 M NH_4Cl extract by the IC and ICP-AES methods, respectively. Water was the least desirable extractant because it removed more organic S than the salt extractants, was the most variable for IC analysis and produced inconsistent results. Poor precision in the SO_4-S determination of the aspen LFH was owing to an elution of an unknown peak adjacent to the sulfur peak. This could possibly be eliminated by changing the mobile phase or anion column.

145. Maynard, D.G.; Stewart, J.W.B.; Bettany, J.R. 1984. Sulfur cycling in grassland and parkland soils. Biogeochemistry 1:97-110. (NoFC)

A conceptual diagram of the S cycle in grassland soils is presented as a framework for discussing S cycling process studies. Changes in the mineralization of S and in the redistribution of ^{35}S-labeled sulfate among soil organic matter fractions were investigated during incubation of cropped and uncropped soils.

Little mineralization or net immobilization of sulfur occurred in closed system incubations where the soils were left undisturbed throughout the incubations. Significantly more S was mineralized in open system incubations where the soils were leached periodically. Net mineralization was significantly greater in cropped soils compared with uncropped soils. The distribution of ^{35}S was significantly affected by the addition of the various substrates (sulfate, cellulose or a combination of both) and by the presence of plants. Under conditions of high solution sulfate, the majority of ^{35}S incorporated was observed in the HI-reducible S fraction. When the solution sulfate concentrations were lower, there was a reduction in the proportion of ^{35}S incorporated into the HI-reducible S fraction. The results of these experiments will be discussed in relation to the hypotheses presented by McGill and Cole (1981) and the conceptual diagram of the S cycle in grassland soils.

146. Maynard, D.G.; Stewart, J.W.B.; Bettany, J.R. 1985. The effects of plants on soil sulfur transformations. Soil Biol. Biochem. 17:127-134. (NoFC)

Changes in the mineralization of S and in the redistribution of ^{35}S-labelled sulfate among organic matter fractions were followed during incubation of cropped and uncropped soils. Net mineralization was significantly greater in cropped soils compared with uncropped soils. The distribution of ^{35}S was significantly influenced by the addition of sulfate or cellulose or a combination of both and by the presence of plants. When the solution sulfate level was high the majority of ^{35}S incorporated into soil organic matter was found in the HI-reducible S fraction. When soil solution sulfate concentrations were lowered by plant uptake or through addition of cellulose there was a reduction in the ^{35}S incorporated into the HI-reducible SW fraction.

147. Millers, I. 1988. North American Sugar Maple Decline Project, Cooperative Work Plan, 8 p., Cooperative Field Manual, 17 p. Can. For. Serv./U.S. Dep. Agric. For. Serv. (CFS-HQ)

Recent reports of decline and mortality in the sugar maple forest type in eastern North America have generated intense interest in the causes of the phenomenon and its geographical extent. In order to address these concerns by an improved definition of the problem and with appropriate research program, the Eastern Hardwoods Research Cooperative is initiating a joint research effort with the Canadian Forestry Service. This effort will be implemented under the existing "Memorandum of Understanding (MOU) between the U.S. Department of Agriculture and Agriculture Canada on Cooperation in the Field of Forestry Related Programs," and the "Project Agreement" under the MOU signed by the Canadian Forestry Service and the U.S. Forest Service for "Sugar Maple Decline Research - Cooperative Project Work Plans."

Because some reports of sugar maple decline have implicated acid rain and other forms of atmospheric deposition as causal factors, it is essential for the interests of both the federal and state/provincial governments to critically review the state of the problem. Patterns of temporal and spatial variation in decline symptomatology will be important in understanding the complex combination of factors which are likely involved in the observed decline. In order to ascribe cause to any single factor or combination of factors, there is a critical need to know the atmospheric deposition burden at the affected sites, as well as the entire range of other biotic and abiotic factors involved.

The proposed first project under the Agreement has the following objectives:

1. to determine the rate of change in sugar maple tree condition ratings from 1988 through 1990;

2. to determine if the rates of change in sugar maple tree condition ratings are different between:
    a. various levels of pollution as measured by wet deposition
    b. sugarbush and undisturbed forest, and
    c. various levels of initial stand decline conditions; and

3. to determine the possible causes of sugar maple decline and the geographical relationship between causes and extent of decline.

The proposed project will augment projects already in progress in the various cooperating agencies and will provide an opportunity to work cooperatively to evaluate the sugar maple decline problem over a greater range of conditions than exists within any one state or province.

A joint work plan will provide for standardized data collection and analysis. Plots will be established in the cooperating states and provinces and allocated to evenly spread the workload and to meet project objectives. Field procedures will be developed during the 1987 field season. Sample plots will be established in 1988, and remeasured twice. Research to explain observed abnormal conditions will be implemented as needed after plot establishment.

148. Mitchell, M.J.; David, M.D.; Maynard, D.G.; Telang, S.A. 1986. Sulfur constituents in soils and streams in the Rocky Mountains of Alberta. Can. J. For. Res. 16:315-320. (NoFC)

Sulfur constituents of soils and streams were measured in the Marmot Basin watershed of the Rocky Mountains (Alberta). Total S in the soils ranged from 2.5 to 49.8 µmol g^{-1} dry mass; carbon-bonded S and ester sulfate were the dominant constituents (67-86% and 5-32% of total S, respectively) with sulfate ranging from 0.1 to 8.1% of total S. Organic S was 12-21% of total S in stream waters. High concentrations of sulfate (93-355 µmol L^{-1}), Ca (763-1075 µmol L^{-1}), Mg (387-765 µmol L^{-1}), and C (1930-4160 µmol L^{-1}) in streams were due to mineral weathering. Atmospheric inputs of S at Marmot Creek were much less important than in forest ecosystems subject to acidic deposition. A tentative budget demonstrated the importance of weathering and organic S in this watershed. Analysis of one tributary (Middle Creek) along an elevation gradient indicated that a portion of the sulfate was retained within the terrestrial portion of the ecosystem in organic forms. The dynamics of these organic S constituents exert a major influence on S flux in some forest ecosystems due to their role in mineralization and immobilization processes.

149. Morrison, I.K. 1983a. Composition of percolate from reconstructed profiles of two jack pine forest soils as influenced by acid input. Pages 195-206 _in_ B. Ulrich and J. Pankrath, eds. Effects of accumulation of air pollutants in forest ecosystems. D. Reidel Publ. Co., Dordrecht, Netherlands. (GLFC)

Two soils, both acid glacio-fluvial sands from beneath mid-aged, natural jack pine (_Pinus_ _banksiana_ Lamb.) forest in northern Ontario, Canada, were reconstructed into 1-m-deep column lysimeters and subjected to dilute H_2SO_4 loadings over 4.5 years. Parameters measured were percolate volume, pH, conductivity, and concentrations of SO_4^{2-}, K^+, Na^+, Ca^{2+}, Mg^{2+} and several trace metals. Results suggest a stage-by-stage process of element loss: first, soils exhibit considerable initial resistance, with SO_4^{2-} movement hampered by strong SO_4^{2-} adsorption; second, SO_4^{2-} adsorption capacity is saturated and bases move freely with SO_4^{2-} ions; third, when bases are depleted, H^+-ions increasingly dominate charge composition, and, concurrently, there is substantial mobilization of trace metals.

150. Morrison, I.K. 1984a. Acid rain: A review of literature on acid deposition effects in forest ecosystems. For. Abstr. 45:483-506. (GLFC)

This report reviews scientific literature of the past decade on the effects of acid deposition within forest ecosystems, with particular reference to forest productivity. It covers mensurational studies together with field and other studies concerned primarily with tree growth. Topics included are artificial acid rain misting experiments used in investigations of foliar and other damages; studies of tree crown interception and leaching; experiments on effects of artificial acidification on soil biota and biological processes; studies of base leaching and its relation to SO_4^{2-}-loading; studies of trace metal mobilization; and the possible relationship of acid deposition to disease and insect attack. In general, on the basis of current literature, it is not yet possible to say that acid deposition does or does not substantially affect forest growth. Other effects have been demonstrated, however. These include enhanced leaching of foliar elements, SO_4^{2-}-related leaching of soil elements, and mobilization of some trace metals. Relationships to forest productivity are considered.

151. Morrison, I.K. 1984b. Acid rain, forests and forestry. Pages 209-219 _in_ E.L. Stone, ed. Forest soils and treatment impacts. Proc. 6th North American Forest Soils Conf., June 1983, Univ. Tennessee, Knoxville, TN. (GLFC)

Selected scientific literature of the past decade on acid deposition and its possible influence on forest health and productivity is briefly reviewed. Topics covered include direct measurements of forest growth, experiments involving applications of artificial acid rain, studies of the influence of acid rain on tree crown leaching, soil blots and biological processes, soil acidification and base leaching, and trace metal mobilization. On the basis of available evidence, it is not yet possible to say that acid rain does or does not significantly affect forest health or growth.

152. Morrison, I.K. 1985. Effect of crown position on foliar concentrations of 11 elements in _Acer saccharum_ and _Betula alleghaniensis_ trees on a till soil. Can. J. For. Res. 15:179-183. (GLFC)

Concentrations of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and Na were examined in whole leaves collected in August 1981 from specified positions within the crowns of 15 Acer saccharum Marsh. and 10 Betula alleghaniensis Britton trees growing in closed forest on a Precambrian-derived till soil in northern Ontario. Concentrations of K, Ca, Mg, Fe, Z, and Na were significantly higher in lower crown leaves of B. alleghaniensis, but in other elements there were no significant differences attributable to crown position. There was a tendency for element concentrations to be higher at all crown positions in intermediate as opposed to codominant trees; however, differences were not significant or were weakly significant at best. Tree-to-tree variation was less in mid- and lower-crown, as opposed to upper-crown, foliage. Generally, for both species, to bring standard errors to within ±10% of the group mean, about 30 trees per stand should be sampled if analyses are restricted to N, P, K, Ca, Mg, and 40-70 trees per stand should be sampled if trace elements such as Mn are to be included.

153. Morrison, I.K. 1988a. Biomass and macroelements in a tolerant hardwood stand, Turkey Lakes Watershed, Ontario. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (GLFC)

Data are presented on the distribution of standing-crop biomass and of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) by components (foliage, live branches, dead branches, stem bark, stem wood, stumps and roots) in an old-growth sugar maple (Acer saccharum Marsh.) - yellow birch (Betula alleghaniensis Britton) stand on a shallow, Precambrian-derived acid till soil in Turkey Lakes Watershed, Ontario. The most abundant element in the standing crop was Ca followed by N > K > Mg > S > P. Presented also, for the same site, are estimates made over a 3-year period of annual total litterfall and of the annual cycle of elements from vegetation to soil by this route. The most abundant element in the annual litterfall was N, followed by Ca > K > Mg > S > P. In addition, data are presented on distributions of total organic matter and of elements in the forest floor of the study stand. The order of elements in the forest floor was N > Ca > S > K > Mg > P. The role of litterfall in replenishing bases removed from the soil through plant uptake and leaching is discussed.

154. Morrison, I.K. 1988b. Effects of artificial acid rain on percolate chemistry of two jack pine forest soils. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (GLFC)

Two soils, both acid glacio-fluvial sands from beneath semi-mature jack pine (Pinus banksiana Lamb.) forest in northern Ontario, Canada, were reconstructed in 1-m-deep column lysimeters in a greenhouse compartment. Over a 5.5-year period, the soils, a Humo-Ferric Podzol from Wells Township, were subjected on a weekly basis to artificial acid rain consisting of H_2SO_4 at pH 2, 3 and 4, together with a distilled water control (pH 5.7). The application rate of the 'rain' was equivalent to 1000 mm per year. Percolates were recovered and volumes were recorded weekly; every fourth week, pH, conductivity and concentrations of SO_4^{2-}, K^+, Na^+, Ca^{2+}, Mg^{2+}, and several trace metals including Al, Mn and Zn were determined. The focus was on soil reactions as interpreted from percolate chemistry. Particular attention was paid to the course of events over time.

The results of the experiment suggest a stage-by-stage process of element loss: first, both soils, but particularly the Humo-Ferric Podzol, exhibited considerable initial resistance to base leaching, with SO_4^{2-} movement hampered by strong SO_4^{2-} retention; second, when SO_4^{2-} adsorption capacity reached the saturation point, bases moved freely with excess SO_4^{2-} ions; third, as exchangeable cations were depleted, H^+-ions increasingly dominated the charge composition; concurrently, with the pH of the percolating solutions declining from 6.5 to less than 4.0 during this stage in soils treated with acid rain having a pH of 2, there was substantial mobilization of trace metals, particularly Al.

155. Morrison, I.K.; Foster, N.W. 1985. Limits on cation leaching of weakly podzolized soils. An empirical evaluation. Pages 377-385 in T.C. Hutchinson and K.M. Meema, eds. Proc. NATO Adv. Res. Workshop on Effects of Atmospheric Pollutants on Forest Wetlands and Agricultural Ecosystems, Toronto, Ont. (GLFC)

Chemical properties of two weakly podzolized sandy soils, one a Humo-Ferric Podzol, the other a less well developed Dystric Brunisol, both from beneath mid-aged jack pine (Pinus banksiana Lamb.) stands in northern Ontario, Canada, are given. In a 7.5-year-old column-lysimeter experiment (reported elsewhere), it had been noted that both soils, but the Podzol in particular, initially exhibited strong resistance to SO_4^{2-} leaching. A hypothesis of anion immobilization by SO_4^{2-} adsorption was advanced. Data to support the hypothesis are presented in the present paper on SO_4^{2-} adsorption characteristics of the two soils. During the initial phase of SO_4^{2-} loading to these soils, cation leaching is effectively blocked by selective removal of SO_4^{2-} ions from the leaching solution and their adsorption chiefly into the Bf1 or Bm1 horizons, and the leaching solution is thereby robbed of counterions. Once SO_4^{2-} adsorption capacity is reached, bases move freely with surplus SO_4^{2-} ions, with the chief limit to removal being the upper limit imposed by the supply of exchangeable ions themselves. Evidence suggests that prolonged exposure to acid solutions may result in increased weathering of silicate minerals of sufficient magnitude to compensate eventually for losses associated with the stripping of exchangeable reserves.

156. Morrison, I.K.; Foster, N.W. 1986. Effects of acid deposition on nutrient cycling in northern hardwood forests. Pages 139-155 in Proc. Conf. on the Northern Hardwood Resource: Management and Potential, Houghton, MI. (GLFC)

The influence of acid precipitation on the ionic composition of throughfall, forest floor percolate and mineral soil solution was examined within two stands of sugar maple and yellow birch at Turkey Lakes Watershed near Sault Ste. Marie, Ontario, Canada. Podzolic soils had developed in silty-loam ablation tills, one derived mainly from granitic materials, the other from a mix of granite and basalt. The granite-basalt till contained higher Ca concentrations, was less acid, and Ca contents of vegetation and litter were higher. Likewise, the mor humus formation was less acid (pH 5.2) and had higher base saturation (61%) on the granite-basalt till than on the granitic material (pH 4.7, base saturation 37%). The acidity of precipitation with an annual volume-weighted pH of 4.4 was reduced by contact with the canopy on both sites and with the forest floor on the Ca-rich site only. The similarity in ionic composition of soil solutions from the two soils suggests that both sites contain sufficient reserves of bases in the forest, humus and mineral soil largely to neutralize present levels of acid deposition and withstand leaching losses of K, Ca, and Mg.

157. Morrison, I.K.; Hogan, G.D. 1986. Trace element distribution within the tree phytomass and forest floor of a tolerant hardwood stand, Algoma, Ontario. Water Air Soil Pollut. 31:493-500. (GLFC)

An examination of tree phytomass and trace metal concentrations (w/w) and pools in the tree stratum and forest floor of a sugar maple - yellow birch forest was carried out at Turkey Lakes Watershed, Algoma District, Ontario. Estimated aboveground tree phytomass (167 500 kg ha^{-1}) was dominated by stemwood, branches 2 cm, and stem bark. Highest trace metal concentrations were found in foliage (Cu, Fe, Mn, Ni) and stem bark (Cd, Pb, Zn). Concentrations of essential trace metals found in all sugar maple components followed the expected sequence of Mn Fe Zn Cu. Lead and Ni concentrations were always higher than those of Cd. Concentrations of essential elements in foliage and other components were comparable to those reported in the literature for other localities in North America. There was no indication that availability of essential trace elements (e.g., Cu) to vegetation had been increased as a result of increased atmospheric deposition. Lead, Ni and Cd levels in vegetation and forest floor were lower than those reported for similar forested areas of the northeastern United States.

158. Morrison, I.K.; Sullivan, C.R. 1981. Terrestrial effects - forest ecosystems. In Acid deposition, knowns and unknowns: the Canadian perspective. APCA (Ont./Que.) Fed. Prov. LRTAP Sci. Comm., Montreal, Que. (GLFC)

This report gives, for a general audience, a brief perspective on the issues followed by a brief review of the current state of knowledge organized under the headings: mensurational studies, acidification experiments and forest productivity/soil fertility relationships. It discusses approaches currently in vogue, viz. experimental approach, biogeochemical approach and estimations of terrestrial sensitivity.

159. Nicolson, J.A. 1984. Ion concentrations in precipitation and streamwater in an Algoma maple-birch forest. Pages 123-135 in Proc. Can. Hydrol. Symp., Quebec City, Que. Vol. 1. (GLFC)

Concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^+, $SO_4{}^{2-}$ and $HCO_3{}^-$ as well as pH, conductivity and alkalinity were measured in bulk precipitation and streamwater collected in 1981 from three small forested basins of 17 to 63 ha at Turkey Lakes Watershed, Ontario. Gross chemical changes in the terrestrial system were measured and ionic contributions to the main aquatic system were determined. Annual unit area flow rates from the three basins averaged 6000 m^3 ha^{-1}; 50% of the total discharge occurred during snowmelt. Contact time of percolating water with soils and unweathered parent material appeared to be important in altering ion concentrations. Highest values for pH, alkalinity, conductivity and most ions occurred in streams from basins with the deepest soil and a high percentage of groundwater in the flow rather than in the shallow soil headwater basin. Ion concentrations in streamwater exceeded those in precipitation in all cases. Bicarbonate ($HCO_3{}^-$ appeared to be important in balancing cation losses in lower-elevation, deeper soil basins, and $SO_4{}^{2-}$ was more important in the shallow-soil headwater basin. Chemical variability among basins in a watershed on the Precambrian Shield can be large, and some terrestrial sites may be sensitive to increased hydrogen ion load.

160. Nicolson, J.A. 1987. Contributions of acid deposition to streamwater chemistry in three Precambrian Shield basins. Pages 89-98 in Proc. IAHS Symp. on Forest Hydrology and Watershed Management, Vancouver, B.C. IAHS Publ. No. 167. (GLFC)

Water and chemical budgets were examined for small undisturbed mature forest basins in three areas across northern Ontario. Precipitation averages, based on four years, varied less than 4% of normal, but variation of streamflow averages, though consistent at all sites, was 25-30% above normal. Sulphate input dominated precipitation at the eastern site and was 2X the SO_4 input at the central site and 3X at the western site. Nitrate was highest in the east, being about 4X greater than at the other two sites. The H input was 5-6X greater at the eastern site. Output was dominated by SO_4, Ca and HCO_3 in the west, HCO_3, Ca and SO_4 at the central site and SO_4, HCO_3 and Ca at the eastern site. Only two cations, H and NH_4, were retained within the basin at all sites; both were highest in the east. All sites lost major cations; the largest loss was at the central site, which had the richest soil. Carbonate in glacial till was important in neutralizing acidity at the central and eastern sites. Results were compared with those of other basin budget studies on the Precambrian Shield.

161. Nicolson, J.A. 1988. Ion movement in terrestrial basins in the Turkey Lakes Forest Watershed. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (GLFC)

Twenty small feeder streams with basins of 4 to 65 ha are being monitored in the Turkey Lakes Forest Watershed (1100 ha) so that their contribution to the main aquatic system can be estimated and gross chemical changes in the terrestrial ecosystem can be measured. Unit flow rates, in five streams selected for presentation in this paper, ranged from 5019 to 6320 m^3/ha/yr with snowmelt providing 38 to 55 percent of total annual discharge. Streams draining headwater areas with shallow soil are generally lower in pH, alkalinity and conductivity than streams of areas with deeper soil at lower elevations in the main watershed. Feeders with large groundwater flow, as is evidenced by annual temperature profiles, have the highest alkalinities and higher values for some major ions primarily because percolating water has more contact time with soils and unweathered parent material. Nitrogen (N) inputs exceeded outputs in four of five watersheds; therefore, N appears to be accumulating in this ecosystem. Output of major cations--calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+)--exceeded input by precipitation in all cases except for K^+ in one watershed. Sulphate-sulphur ($SO_4{}^{2-}S$) input and output are nearly in balance in four basins. Bicarbonate, as reflected by alkalinity values, was more important in balancing cation losses in areas of lower elevation and deeper soil, while sulphate appears to play this role in shallow-soil headwater basins. Chemical variability between streams in a watershed can be large and some areas are sensitive to increased hydrogen (H^+) ion load.

162. Nicolson, J.A.; Craig, D.; Foster, N.W. 1987. Acid precipitation, surface and subsurface water chemistry in a tolerant hardwood forest basin. Pages 91-100 in Proc. Int. Symp. on Acidification and Water Pathways, Bolkesjo, Norway. (GLFC)

Water quality in the terrestrial portion of the Wishart Lake basin in the Turkey Lakes Watershed, Ontario, was characterized in 1983. Ion concentrations in precipitation, soil water, groundwater at depths up to 7 m, and streamwater at two locations were examined. Mean annual H^+ concentrations decreased while alkalinity and Ca^{2+} increased with depth below the soil surface and with the length of the groundwater flow path. Solutions were dominated by Ca^{2+} and $SO_4{}^{2-}$ in the unsaturated and shallow groundwater zones and in streams, and by Ca^{2+} and alkalinity in deeper groundwater. Lower alkalinity and Ca^{2+} concentrations in one stream suggested that it received a greater proportion of water from shallow groundwater and hence was more sensitive to acid inputs. With respect to watershed acidification, $SO_4{}^{2-}$ from atmospheric acid deposition was supplemented by $SO_4{}^{2-}$ released from the soil zone. Geochemical weathering of carbonates in the till was the major reaction controlling groundwater alkalinity, and through groundwater discharge, streamwater alkalinity. Biotic and abiotic reactions in the basin seem to be regulating drainage water chemistry more than the chemistry of precipitation.

163. Nicolson, J.A.; Foster, N.W.; Morrison, I.K. 1982. Forest harvesting effects on water quality and nutrient status in the boreal forest. Pages 71-89 in Proc. Can. Hydrol. Symp. '82, Fredericton, N.B. (GLFC)

Man, through harvesting and site preparation, can create major disruptions of nutrient and hydrologic cycles in forest ecosystems. Nutrient losses occur by direct removal in harvested materials and by accelerated leaching to surface runoff or percolation to groundwater.

Several small (35-170 ha) basins representing uncut and clearcuts of various ages were monitored in the jack pine (Pinus banksiana Lamb.) - black spruce (Picea mariana (Mill.) B.S.P.) type in northwestern Ontario. They were selected on the premise that major disruptions should be detectable by studying a cross-section of basins in each category.

Weekly sampling occurred during the biologically active portion of the year (April-October). Concentrations of elements increased following disturbance but returned to precut levels by the second year. However, the greater volume of water flushing through the ecosystem, because of reduced evapotranspiration, resulted in additional nutrient losses from the site for several years.

By means of a considerable body of biomass and soil element data from the jack pine type throughout Ontario, it was possible to establish the significance of losses by crop removal based on depletion of "available" nutrient reserves. Losses from the tree-plus-soil nutrient pool through direct removal by conventional shortwood harvesting may reach 35% of N, 20% for P, and lesser though still substantial portions for Ca and Mg. On a larger scale the significance of water quality changes due to forest management activities is discussed in relation to the Great Lakes Basin.

164. Nyborg, M.; Crepin, J.; Hocking, D.; Baker, J. 1977. Effect of sulfur dioxide on precipitation and on the sulfur content and acidity of soils in Alberta, Canada. Water Air Soil Pollut. 7:439-448. (NoFC)

Rain and snow in Alberta are seldom acid. The S content of snow is so low that the snow pack gives a deposition of less than 1 kg S ha^{-1}, even downwind from large SO_2 emission sources. Rainfall contributes at the most 4 kg S ha^{-1} yearly near SO_2 sources, and only about 1 kg S ha^{-1} in clean areas. However, rain intercepted by forest trees exposed to SO_2 emission becomes acid (pH 3.5 to 4.5) and has a S content of 3 to 4 times greater than rain. Soils absorb large amounts of S from emissions (up to 50 kg S ha^{-1} annually) but much of the S is found in non-sulfate form. Soils are slowly acidified by the SO_2 at a rate estimated at 1 pH unit in 10 to 20 yr. Water surfaces will absorb SO_2 emissions at a rate of about 4 to 15 kg S ha^{-1} annually. Particulates deposit 3 to 4 times as much as is deposited by rainfall.

165. Percy, K.E. 1983a. Heavy metal and sulphur concentrations in *Sphagnum magellanicum* Brid. in the Maritime Provinces, Canada. Water Air Soil Pollut. 19:341-349. (CFS-M)

A regional survey of selected heavy metals and S concentrations in *Sphagnum magellanicum* Brid. was completed within the Maritime Provinces, Canada. The concentrations of Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, S, and Zn were used to describe regional atmospheric deposition patterns to the terrestrial surface. There are measurable inputs of all elements. The elements were accumulated in the order S > Fe > Mn > Zn > Pb > Cu > Ni > Cr > Co > Hg > Cd. The regional mean concentrations for the anthropogenically derived heavy metals were lower than levels reported for northern Ontario and southern Sweden. There are no comparable data for S concentrations in *Sphagnum* spp. High concentrations of Pb, Hg, and S were attributed to local anthropogenic emissions. Significant correlations in concentration were determined between the element pairs Fe-Co and Ni-Cr.

166. Percy, K.E. 1983b. Sensitivity of eastern Canadian forest tree species to simulated acid precipitation. Aquilo Ser. Bot. 19:41-49. (CFS-M)

The growth and morphological responses of 14 eastern Canadian forest tree species to simulated acid precipitation are being investigated. The effects of four treatment pHs (5.6, 4.6, 3.6, 2.6) on seed germination rate and capacity, seedling development including height and productivity components, and seedling morphology including foliar numbers and length are being examined. Histological-histochemical techniques are used to assay microscopic alterations in foliar anatomy, carbohydrate and protein metabolisms, and enzyme activities. Modifications in surface features are studied under the scanning electron microscope. The experiments are occurring in a laboratory, controlled-environment system which simulates rain chemistry (16 ions), rain volumes, rain intensity, and raindrop characteristics typical of a previous growing season in central New Brunswick.

Preliminary data from three Pinaceae indicate a large degree of interspecific variation for seedling response in most morphological parameters. Highly significant decreases in germination rate and capacity at pH 2.6 occurred in white spruce (Picea glauca (Moench) Voss) and red spruce (Picea rubens Sarg.). No such trends were observed in red pine (Pinus resinosa Ait.) or jack pine (Pinus banksiana Lamb.). Increasing rain acidity tended to decrease seedling growth. Significant inhibition of primary and/or secondary needle initiation was observed in the four species at pH 4.6. Other parameters were less consistently affected.

167. Percy, K.E. 1986. The effects of simulated acid rain on germinative capacity, growth and morphology of forest tree seedlings. New Phytol. 104:473-484. (CFS-M)

Acid rain-induced direct injury to forest tree seedlings was investigated in specially designed controlled-environment simulated-rainfall chambers. Seed germinative capacity, seedling survival, seedling growth and morphological responses to simulated rains of pH 5.6, 4.6, 3.6 and 2.6 were examined during the first growth cycle in 11 commercially important north temperate tree species. Germinative capacity was weakly responsive to rain pH, while seedling survival was more sensitive. No evidence of macroscopic foliar injury was observed at rain pH > 2.6. Treatment with pH < 4.6 rain was sufficient to induce statistically significant growth reductions and morphological changes in coniferous seedlings. Response varies with species, treatment pH and parameter measured. No consistent growth stimulations were observed. Initiation of primary needles, axillary meristems and shoot apex height were most affected by simulated pH. Deciduous species were considerably more resistant than coniferous species. Treatment with rain of pH 2.6 was generally required to induce significant growth reductions in deciduous seedlings.

168. Percy, K.E. 1987. Effects of simulated acid rain on leaf cuticular characteristics and leaf surface properties. PhD thesis, Univ. Bristol, UK. (CFS-M)

The effects of simulated acid rain (SAR) on adaxial leaf cuticles were investigated for a group of plant species selected from commercially important crops and trees which exhibited markedly different cuticular characteristics. Expanding leaves of controlled-environment grown plants were exposed from emergence to full expansion to pH 5.6, 4.6, 4.2, 3.8, 3.4, 3.0 or 2.6 simulated rain applied at 2 mm h^{-1} on alternate days. The number of rain events, amount and droplet size (349 µm diam.) and velocity (1.2 m s^{-1}) were representative of UK ambient rainfall characteristics. The "non-acidic" pH 5.6 simulated rain consisted of 14 inorganic ions in weight/volume concentrations equivalent to those measured at a site in eastern Canada.

The degree of foliar injury and size of lesions were greater on crop species with "waxy" leaves than "non-waxy" leaves. Injury was least on needles of the coniferous species Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The relative sensitivity of the species to foliar injury decreased in the order: field rape (*Brassica napus* L.) > Eucalyptus (*Eucalyptus globlus* L.) > pea (*Pisum sativum* L.) > dwarf bean (*Phaseolus vulgaris* L.) > field bean (*Vicia faba* L.) > Sitka spruce.

Epicuticular wax production, structure and composition on leaves exposed to SAR were affected to varying degrees in all species. Wax quantity decreased on the adaxial leaf surfaces of dwarf bean, field bean, pea and Eucalyptus exposed to SAR at one or more pH's < 4.6 but was unaffected in field rape and Sitka spruce. Effects on crystalline wax structure at pH < 4.6 ranged from an increase in the proportions of smaller crystallites on field rape (tubes) and pea (plates) leaves to the complete modification of fine crystalline structure on Sitka spruce needles. Changes in wax composition were usually restricted to leaves whose waxes comprised one constituent class with one predominant homologue. The amount of primary alcohols decreased on dwarf bean leaf surfaces exposed to SAR at pH < 4.6 while the relative proportions of diols recovered in wax from Sitka spruce needles exposed at pH < 4.2 increased or decreased depending upon clone.

Cuticular membranes were up to 50% thinner in dwarf bean, field bean and pea leaves exposed to SAR at pH < 4.2. Membrane thickness in Sitka spruce needles exposed at pH < 4.2 increased or decreased depending upon clone. Membrane ultrastructure was only affected in dwarf bean.

Consequential to the changes in physico-chemical cuticular characteristics, contact angles were decreased on leaves or needles of all species exposed at pH < 4.6. These changes resulted in increased retention of SAR by dwarf bean and field rape leaves as well as by Sitka spruce needles exposed at pH < 4.2.

Changes in leaf surface properties often led to changes in foliar uptake of $^{86}Rb^{+}$, $^{63}Ni^{2+}$ or $^{35}SO_4{}^{2-}$ radioisotopes applied using droplet sizes and velocities representative of ambient rainfall to intact leaf surfaces. Uptake of one or more isotopes was decreased in field rape leaves exposed at pH < 3.4 and increased in dwarf bean and Eucalyptus leaves exposed at pH < 3.0. Uptake of $^{86}Rb^{+}$ was increased at pH 2.6 in one clone of Sitka spruce. Only small proportions (<6%) of recovered activities were found in crystalline epicuticular wax layers. Ion mobility within leaves or needles was only affected at pH 2.6. Greater proportions of recovered activities were found in the cuticle-epidermis layers in mutant pea (Pisum sativum L. Arg.) leaves than were found in the epicuticular wax layers on leaves of other species.

169. Percy, K.E. 1988. Direct effects of acid rain on the morphology and growth of forest vegetation. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (CFS-M)

Research into the direct effects of acid rain on vegetation has gained much attention during the past few years. In this paper, a review of the current knowledge regarding these effects as they pertain to the morphology and growth of forest vegetation has been presented. Currently, there is no conclusive, unequivocal field evidence for a direct effect of ambient rain on forest growth although acid rain and/or air pollutants in general have been much discussed as contributing to forest declines or growth reductions in forests in the United States and Europe.

The data presented here suggest that the direct interaction between acid rain and plant foliage can alter the morphology and growth of seedlings of many forest tree species. However, there are many factors that may determine plant response to isolated extremely acid events or, alternatively, to a succession of less acid ones. While current knowledge has added to an understanding of the process of direct injury, numerous questions remain unanswered. Laboratory studies should not be taken out of the context in which they were performed and applied to the field in either a predictive or a quantitative manner. Rather, they should be regarded as indicators of specific potential effects which could occur in the field under certain conditions. Serious consideration should also be given to the inclusion of combinations of pollutants in experiments where possible and applicable. Well-designed field experiments able to detect subtle effects will need to be established in order to document direct effects in the field, which could then be applied on a wider basis.

170. Percy, K.E.; Baker, E.A. 1987a. Effects of simulated acid rain on production, morphology and composition of epicuticular wax and on cuticular membrane development. New Phytol. 107:577-589. (CFS-M)

Leaves of *Phaseolus vulgaris* L., *Vicia faba* L., *Pisum sativum* L. and *Brassica napus* L. were exposed to simulated rain from emergence to full expansion at seven pHs between 5.6 and 2.6 applied at 2 mm h^{-1} in amounts and at intervals representative of ambient rain in southwestern England. Leaf expansion was unaffected by rain pH greater than 3.0 in *V. faba*, and pH 2.6 in the other species. Macroscopic foliar injury was induced at pH < 3.4 in non-wettable *P. sativum* and *B. napus* leaves which had relatively large deposits of crystalline epicuticular wax, and at pH 3.0 in wettable *P. vulgaris* and *V. faba* leaves which had small deposits of amorphous wax. Foliar injury was greatest in species with crystalline wax. Wax production was affected by simulated acid rain in all species and was often accompanied by changes in wax composition. Wax quantity was reduced on *P. vulgaris* leaves exposed to rain at pH < 4.6 while wax on *P. sativum* and *B. napus* leaves had increased numbers of smaller plates and tubes respectively per unit area at pH < 4.6. Leaves of *B. napus*, stripped of crystalline epicuticular wax at about 20% full expansion, regenerated less wax at pH 3.4 than at pH 5.6. The thickness of the cuticular membranes in *P. vulgaris*, *V. faba* and *P. sativum* leaves exposed to simulated acid rain at pH < 4.2 decreased by 28 to 35% compared to those exposed to pH 5.6 rain. Membrane ultrastructure was also altered in *P. vulgaris* leaves. Taken together, these changes could have important consequences for leaf wettability, rainfall retention, foliar uptake of chemicals and host-parasite interactions.

171. Percy, K.E.; Baker, E.A. 1987b. Effects of simulated acid rain on leaf wettability, rain retention and uptake of some inorganic ions. New Phytol. 108:75-82. (CFS-M)

Leaves of *Phaseolus vulgaris* L., *Vicia faba* L., *Pisum sativum* L. and *Brassica napus* L. were exposed from emergence to full expansion to seven treatments of simulated acid rain at pHs between 5.6 and 2.6. Droplet leaf contact angles in all species decreased on leaves exposed to simulated acid rain at pH < 4.6 relative to those exposed at pH 5.6. Retention of rain containing fluorescein increased on *P. vulgaris* leaves exposed to simulated acid rain at pH 4.6 and at pH < 3.8. Retention by *B. napus* leaves was increased at pH < 4.6. Uptake of the three ions studied was in the order $^{86}Rb^{+}>^{35}SO_4^{2-}>^{63}Ni^{2+}$. Uptake of $^{86}Rb^{+}$ increased into *B. napus* leaves and decreased into *P. vulgaris* leaves exposed at pH < 3.4. Uptake of $^{35}SO_4^{2-}$ and $^{63}Ni^{2+}$ by B. napus leaves increased after exposure to simulated acid rain at pH 2.6 but it was unaffected in P. vulgaris. Up to 7% of applied $^{35}SO_4^{2-}$ was found in the epicuticular wax layer on B. napus leaves 48 h after application, most being found after exposure at pH 2.6. The order of ion lateral movement within leaves paralleled the order of uptake. Movement of all three ions was increased in B. napus leaves exposed previously to simulated acid rain at pH 2.6. The increased retention of fluorescein on leaves exposed to simulated acid rain and the reduced contact angles for water are attributed to decreases in surface roughness. The altered ion uptake pattern could also be related to changes in surface wax structure or could be associated with observed changes in properties of cuticular membranes. These results demonstrate that the interaction of plants with their atmospheric environment could possibly be affected by pre-exposure to acid rain in amounts and at pH values that occur in ambient rainfall.

172. Percy, K.E.; Borland, S.A. 1985. A multivariate analysis of element concentrations in Sphagnum magellanicum Brid. in the Maritime Provinces, Canada. Water Air Soil Pollut. 25:331-338. (CFS-M)

The concentrations of 14 elements (Ca, Cr, Cu, Fe, Hg, K, Mg, Mn, N, Na, Ni, Pb, S, Zn) were measured in Sphagnum magellanicum Brid. collected from 61 ombrotrophic bog sites in the Maritime Provinces, Canada. Principal component analysis was used to explain the variability in element concentrations in terms of underlying biological or source variables. Fifty percent of the elements and 77% of the variation measured can be accounted for by six principal components. Components relating to the physiological-nutritional status of the plants and the sources of inputs for the most important elements were explained. It is suggested that concentration of K in Sphagnum magellanicum can be used as an indicator of plant nutritional status, and that concentrations of Na, Ni and Fe can be used as indicators of atmospheric inputs from sea salt aerosols, fossil fuel combustion, and natural crustal or soil-derived lithophile elements, respectively. Sulphur concentrations in S. magellanicum did not provide an accurate measure of long-range or local anthropogenic input.

173. Percy, K.E.; Riding, R.T. 1978. The interaction of air pollutants with the epicuticular waxes of Pinus strobus. Can. J. For. Res. 8:474-477. (CFS-M)

The interaction of air pollutants with the epicuticular waxes of eastern white pine (Pinus strobus L.) needles was investigated. The morphology and distribution of waxes differed between needles from trees growing in locally polluted and unpolluted atmospheres. On needles subjected to air pollutants stomatal occlusion was prominent and structural wax integrity was disrupted. Epicuticular wax modification may be an initial effect of air pollutants.

174. Percy, K.E.; Riding, R.T. 1981. Histology and histochemistry of elongating needles of Pinus strobus subjected to a long-duration, low-concentration exposure of sulfur dioxide. Can. J. Bot. 59:2558-2567. (CFS-M)

Two-year-old seedlings of Pinus strobus were grown from budbreak to bud set (11 weeks) in air containing 132 ± 26 µg SO_2 m^{-3}. Histological and histochemical effects on elongating needles were examined. Cellular injury was restricted to mesophyll parenchyma. Affected cells manifested a progressive alteration of protoplast staining proportional to the degree of injury. Total carbohydrates and plastids aggregated at cell walls. Total proteins and proteins containing sulfhydryl-disulfide groups decreased. Phospholipid staining in the plasmalemma - cell wall region appeared reduced. Succinic dehydrogenase activity was enhanced and was apparent longer in injured cells. Needle ontogeny was slowed in fumigated seedlings. There were no significant differences in external growth parameters after 11 weeks. The injury can, therefore, be classified as latent or hidden. The SO_2 effects could contribute to a growth reduction in successive increments.

175. Pollard, D.F.W. 1983. Carbon reservoirs in Canadian forests. Pages 19-24 in Rep. Tech. Meet. on Sources and Sinks of Atmospheric CO_2 in Northern Latitudes, Atmos. Environ. Serv., Environ. Can., Toronto, Ont. (CFS-HQ)

The structure of Canada's forests is examined from the standpoint of the forest's ability to accumulate carbon. Lack of consistent data, especially over reasonable intervals of time, renders the assessment extremely rough at present, and even greater gaps occur in our knowledge of forest soils, whose carbon content greatly exceeds that of the living biomass they support.

176. Pollard, D.F.W. 1985. A forestry perspective on the carbon dioxide issue. For. Chron. 61:312-318. (CFS-HQ)

The global atmosphere is being enriched with carbon dioxide through the combustion of fossil fuels and reduction of forest biomass and soil organic matter. The estimated preindustrial concentration of 260 parts per million by volume is expected to be doubled by the year 2065, with consequential disturbances in global and regional climates. Enrichment will certainly have direct impacts on the forest sector, probably favouring fast growing species, in particular certain hardwoods and weed species. An antitranspirant effect of CO_2 may also improve growth rates and water economies, especially in arid regions. Impacts of climatic disturbance are much more difficult to predict, largely because of uncertainty in current climate response theory. Best available information indicates the development of a serious mismatch between Canadian forests and the climatic regions they will occupy. When viewed as empirical models of climate change, past climate variations suggest that forest pest problems will intensify. Judicious analysis and research will enhance realization of opportunities and reduce impacts of future conditions, particularly as presented by CO_2-enriched atmospheres.

177. Pollard, D.F.W. 1988a. Forestry in a changing climate. In R.R. Street, D.C. MacIver, and A.N. Auclair, eds. Climate applications in forest management and forest production. Forest Climate '86, Symp./Workshop, Orillia, Ont. Can. For. Serv., Atmos. Environ. Serv., Ottawa, Ont. (in press). (CFS-HQ)

Accelerating increase in atmospheric carbon dioxide and other gases resulting from industrial activity will lead to dramatic changes in climate in the twenty-first century. Foresters are confronted with the issue now, because they plan and initiate operations that extend over many decades. Forest ecosystems are sensitive to climate, and the projected climatic scenarios suggest an increase in biological production. But empirical models that relate vegetation to climate indicate that a severe mismatch may develop between Canada's forest regions and the climatic regions they occupy. Fire, insect pests, diseases and weeds will respond quickly and strongly to changes in climate, and under the currently projected scenarios may assume critical proportions in the forest sector. Nevertheless, the promise of increased biological productivity, through longer, warmer seasons, enhanced efficiency of water use by plant species, and carbon dioxide enrichment, offers a significant challenge and opportunity to foresters equipped for intensive forest management.

178. Pollard, D.F.W. 1988b. Forestry and climate change: facing uncertainty. E.B. Eddy Distinguished Lecture Series, November 1987. Univ. Toronto Press, Toronto, Ont. (CFS-HQ)

Scenarios of climate change caused by increases in radiatively active gases are reviewed. Impacts on forestry are expected to occur as forest ecosystems become progressively less adapted to the changing climates they experience. Impacts could include increased severity and incidence of pest and disease outbreaks, competition from weeds, fire, freeze-thaw activity, and freezing rain. Winter forest operations could be severely hampered in regions dependent on freeze-up for access to and through wetlands. Benefits could accrue from forest growth rates in response to increased availability of carbon dioxide and associated enhancement of water-use efficiency and nitrogen fixation and to longer, warmer seasons. Strategies to mitigate impacts are discussed, and current research and policy-related activities are outlined.

179. Rao, D.N.; Robitaille, G.; LeBlanc, F. 1977. Influence of heavy metal pollution on lichens and bryophytes. J. Hattori Bot. Lab. 42:213-239. (LFC)

This review article examines the literature up to 1977 on the absorption and accumulation of heavy metals as affected by morphology, substrate, acid rain and climate. It examines the process of accumulation and toxicity. Metal tolerance and detoxification are also reviewed. The monitoring and mapping of metal pollution are also discussed.

180. Rencz, A.N.; Percy, K.E.; Kettles, I.M. 1985. Predicting terrain sensitivity to acid rain: scientists integrate data sets. Geos 14:21-25. (CFS-M)

In this study, emphasis was placed on merging data sets to better estimate a region's overall sensitivity to acid rain. The conclusions drawn from combined data sets are not necessarily identical to those drawn from a single data set. For example, in this study it was shown that highly sensitive deciduous forests can grow on glacial sediments having very different concentrations of calcium carbonate. When this variation is taken into account, the overall sensitivity rating for deciduous forests on carbonate-rich soils is lower.

In addition, conclusions for overall sensitivity from this study can be drawn at two levels--one detailed (10s to 100s of metres) and the other regional (10s to 100s of kilometres). The detailed information is required to represent environmental, particularly forestry, variability. The regional information is needed to delineate large-scale trends.

181. Rennie, P.J. 1978. Ecosystem responses to environmental pollutants. Pages 139-144 in Proc. Air Quality Criteria Workshop, Atmos. Environ. Serv., Toronto, Ont. (CFS-HQ)

The presentation explores the difficulty and limitations of air-quality standards when they are used to preserve the quality of environmental components threatened by sub-standard and long-continued concentrations of potentially noxious elements that can bring about permanent environmental degradation. Some general ecosystem characteristics of air, water, soil and vegetation relationships are explained and particular Canadian sensitivities and threats emphasized. Suggestions are made for broadening the traditional concept of what is required of an air-quality criterion, and pointers are given as to areas of understanding in need of improvement to provide a better scientific basis for developing air-quality standards.

182. Rennie, P.J. 1979a. Dangers to soils and vegetation. Pages 24-29 in Damages and Effects Session, Proc. Action Seminar on Acid Precipitation--an International Citizens' Conference on Acid Rain, Toronto, Ont. (CFS-HQ)

This is a non-specialist account of acid rain and its implications for Canadian forests. The presentation dealt with the economic and environmental values of the forest resource, the nature of the terrestrial environment, the threat of acid rain, the specific Canadian concerns, and the terrestrial acid-rain research program. Tapes of all presentations were prepared for wide distribution.

183. Rennie, P.J. 1979b. Long-range pollution and acid rain: factors in the terrestrial environment. Pages 35-44 in Proc. Workshop on Long-Range Transport of Air Pollution and Its Impacts on the Atlantic Region, Atmos. Environ. Serv., Dartmouth, N.S. 108 p. (CFS-HQ)

Explained is how long-range pollution is a threat to eastern Canadian vegetation and soils. The diffusion of pollutants through ecosystems is illustrated by the interconnecting pathways among the components--vegetation, soil, water and wildlife. The difference between strong point emissions and long-range pollution is shown to affect the experimental approaches able to investigate the two problems, and suggestions are made for a multi-disciplinary catchment basin approach where the path, transformations and effects of the deposited pollutants can be accurately followed all the way from the atmosphere to the river systems.

184. Rennie, P.J. 1979c. Terrestrial systems. Pages 18-32 in A.P. Altshuller and G.A. McBean, eds. The LRTAP problem in North America: a preliminary overview. Prepared by the United States - Canada Research Consultation Group on the Long-Range Transport of Air Pollutants. (CFS-HQ)

This is part of a larger review of current knowledge on regional air pollution, dealing with pollutant emissions, atmospheric chemistry, transboundary fluxes, deposition levels, and effects on aquatic and terrestrial ecosystems. Although effects on aquatic systems have been clearly recognized, those on terrestrial systems, especially forests, are at this time ambiguous. The forests and soils of large areas of the northeast appear unimpaired so far, but several lines of evidence suggest they are at risk. The first comes from over 70 years of experience near strong point sources of pollutants; the second comes from the degradation in soil properties and fertility recorded following long-continued application of acidic fertilizers; the third comes from the well-known adverse changes in soil properties--increased mobilization of the toxic elements aluminum and manganese, extinction of useful microorganisms--that are associated with increased soil acidification; the fourth comes from the steadily improving knowledge of pollutant levels and mixtures present in the northeast; the fifth comes from the generally nutrient-poor and already extremely acidic nature of most soils in the northeast that support forests; and the sixth factor is the tremendous economic value and wider environmental importance of the forests of the northeast. Factual evidence is provided with literature sources.

185. Rennie, P.J. 1980a. North American energy policy: environmental perspectives and energy needs. In Proc. 73rd Annu. Meet. Exhib. Air Pollut. Control Assoc., Montreal, Que. Pap. No. 80-25.1. (CFS-HQ)

The supply of primary materials and energy on the one hand and the manufacturing of a variety of everyday products on the other hand are seen as two main activities of a modern industrialized society whose needs and sensitivities may not be mutually understood. The conflicts that may result from this insensitivity are explored, especially in relation to future energy needs, projected coal consumption and air pollution, with the latter's threat to forest production and other renewable resources. The need is seen to develop mutually acceptable cultural practices and methodologies.

186. Rennie, P.J. 1980b. Acid rain and the forest: a serious but elusive threat. Can. Pulp Pap. Ind. 33:23-33. (CFS-HQ)

This is an objective and not too specialist account, prepared especially to inform the forester and practitioner of the debate on acid rain and the cause for concern in forestry circles. Sections deal with: acid rain and long-range pollution; acid rain and acid gases; forests affected; sources of acid rain; future trends; effects on forest vegetation; effects on forest soils; an acid rain program; key tasks.

187. Rennie, P.J. 1980c. Effects of atmospheric deposition. In A.P. Altshuller and G.A. McBean, eds. Second Report of the United States - Canada Research Consultation Group on the Long-Range Transport of Air Pollutants, November. Chap. 4 (CFS-HQ)

The chapter is designed to supplement the previous year's Report (17 October 1979) on the evidence for the cause of concern. The chapter contains sections on - introduction; extent of sensitive land/water regimes; effects on ecosystems; understanding the mechanisms of effects; effects on crops and forests; effects on aquatic ecosystems; human health implications of LRTAP; water quality; other long-range airborne contaminants of concern; and visibility. Provided is a bibliography reflecting CFS contributions and a figure showing a ranking of the sensitivity of the soils of eastern Canada to acid rain. The Report is available in English and French.

188. Rennie, P.J. 1983a. United States - Canada memorandum of intent on transboundary air pollution. Impact Assessment Work Group No. 1, Final Report. Summary - Terrestrial Ecosystem Impacts, Ch.1/13-1/16. Terrestrial Impacts, Ch. 4/1-4/116. (CFS-HQ)

This is the final or Phase III Report, considerably expanded from the earlier Phase II or interim Report of 1981. All quality literature is reviewed to yield a comprehensive state-of-the-art critique on the effects of long-range air pollution on forests, soils, crops and wildlife.

Effects on Vegetation: Three main pollutants are of concern: sulphur dioxide, ozone, and acidic deposition. Ozone and acidic deposition occur at concentrations above background levels at long distances from emission sources. Sulphur dioxide is more of a local concern.

(1) Sulphur Dioxide: Near point sources, the adverse effects of SO_2 on vegetation can be both visible and subtle (without development of visible foliar injury). Visible effects can be associated with doses of both high concentrations of SO_2 over short periods of time and low concentrations over extended periods. However, in a few specific cases, atmospheric SO_2 deposition may have beneficial effects on agricultural vegetation grown on borderline or sulphur-deficient soils.

Visible effects of SO_2 have occurred on pine forests in Canada subjected to average growing season concentrations of sulphur dioxide of 0.017 ppm. Visible injury to the perennial foliage of coniferous trees results in premature needle drop, reduced radial and volume growth and early death of trees. Reduced growth and yield of crops without the development of visible injury have also been found in certain field experiments.

Annual doses of SO_2 of 0.02 ppm have been associated with habitat modifications in grasslands and the elimination of certain sensitive species of lichens near point sources. Lichens may be markedly affected and are considered as bioaccumulators of very low level exposures. Direct effects including visible injury, effects on reproductive capacity and species mortality have been encountered in the field at concentrations as low as 0.006-0.03 ppm annual average.

Despite such documented evidence of instances of direct effects, obviously not all but probably most exposures to SO_2 on a regional scale are below levels producing phytotoxic reactions. However, long-term, low-dose studies have demonstrated direct effects on lichen communities and indirect effects on several plant species.

(2) Ozone: Ozone is the most important long-range transported pollutant with respect to vegetation effects. Air masses carry ozone and its precursors over long distances and can affect crops and forests in rural areas remote from sources. As a specific example, ozone-related crop injuries in southern Ontario have been reported associated with high ozone levels in air masses moving across Lake Erie. In the U.S., experimentally derived crop yield losses ranging from 2 to 56% (crop dependent) were equated with seasonal 7 h d^{-1} mean ozone concentrations of 0.06-0.07 ppm. Yield losses in the various crops were as follows: kidney bean 2%, soybean 10%, peanut 14-17%, and lettuce 53-56%. Although direct effects of ozone have been documented on forest growth, an estimate of loss is difficult to calculate because of the limitations discussed in the main report.

(3) Acidic Deposition: Acidic deposition in the form of simulated rain has been demonstrated to induce a variety of direct and indirect effects on plants grown under greenhouse or semicontrolled conditions. Foliar injury, growth reductions, and growth stimulations have been found under these growing conditions following treatment with simulated acidic precipitation. However, visible foliar injury has not been documented in the field for vegetation exposed to ambient levels of acidic precipitation. Potential effects on forest growth have been difficult to predict because of the complicating influences of other environmental and climatic factors. To date, there have been too few studies to establish a clear relationship on the interactions of acidic deposition/sulphur dioxide/ozone to reach a definitive conclusion on effects.

Effects on Terrestrial Wildlife: Direct effects of acidic deposition on terrestrial wildlife have not been reported and are not considered likely. Nevertheless, in some instances, indirect effects have been suggested through three possible mechanisms:

(1) contamination by heavy metals mobilized by acidity;

(2) reduction in nutritional value of browse or food source; and

(3) loss of browse species or impairment of habitats.

Effects on Soil: Soils vary widely with respect to their properties, support different vegetation communities, are subjected to different cultural practices, are situated in different climatic zones, and are exposed to a broad spectrum of acid loadings. The following effects probably occur and in some cases are supported by observation, although the number of field situations where investigators have been able to attribute acidity to precipitation or to compare present with former soil pH values is small.

On soils derived from calcareous parent materials, the effects of acidic deposition will lead to only insignificant increases in lime requirement, except in situations near strong point emitters. Heavy metal deposition near point-source emitters may cause soil toxicities.

On acid soils, the absence of clear effects upon tree growth from radial-increment measurements covering several decades suggests there will be no short-term effects attributable to acidic deposition.

From the few field situations where earlier investigations permit a comparison over a reasonable time-frame, there is evidence that less acutely acid soils increase in acidity and lose bases at a faster than normal weathering rate. For acutely acid soils, pH may show only minor changes, while over the same period moderate to appreciably larger amounts of soil aluminum are mobilized. This depends upon whether the forest cover is deciduous (e.g., beech) or coniferous (e.g., spruce).

From one comprehensive field investigation, it has been suggested that the additional amounts of aluminum brought into solution kill feeding roots and permit the invasion of fungi causing tree "dieback," but it is not known whether this phenomenon would occur on other sites and soils. What appears well established from a variety of hydrological, limnological and catchment studies is that acidic deposition can lead to the release of additional amounts of soluble aluminum, thus disturbing previous aluminum/calcium ratios in soils, sediments and streamwaters. An eventual reduction in base status and fertility is suggested.

The sulphate component of acidic deposition appears to be absorbed by soils containing active aluminum and iron oxides, but where these are absent or present in limited amounts, sulphate functions as a balancing anion, leading to the leaching loss of bases and other cations.

The fate of the nitrate component depends upon wet precipitation/snowmelt characteristics. Nitrate reaching the surface organic horizons of acid forest soils is held there for assimilation by tree roots during the growing season. There are, however, forested catchments in the northeast where nitrate is passed to water bodies.

The lack of appropriate experimental approaches from which the effects of acidic deposition on soil might be assessed and safe deposition ceilings estimated has caused scientists to exploit indirect or special situations. These include working near strong point sources, studying soils treated with acidifying fertilizers, and designing lysimetric experiments incorporating simulated acid rains. From such approaches, a variety of soil effects have been demonstrated, usually of an undesirable nature, but at the present time the problem remains of quantifying dose-response reactions in the field situations.

Sensitivity Assessment: Regions which may be sensitive to acidic deposition have one or more components (i.e., forests, aquatic life, soil, or water) susceptible to degradation under the influence of acidic deposition. Relative sensitivity of these components is reflected in the rate at which an ecosystem component degrades under a particular acidic deposition loading. Different underlying criteria have to be used to represent sensitivity for the different ecosystem components, such as rate of tree growth, characterization of the soil-base status, or water alkalinity. Because so little is known about the acidic deposition dose-response relationships, the underlying criteria are often imprecise. Therefore, relative sensitivity can only be approximately represented or mapped, and then perhaps for only a few species, ecosystems or theoretical effects.

Attention is focused on the sensitivity of soils and bedrock because results from studies which address vegetation and ecosystem effects are limited and not well understood at this time. In the approach used, the emphasis has been to map a combination of potentially important soil attributes as a best available indicator of relative sensitivity. Soil attributes incorporated include texture, depth to carbonate, pH and cation exchange capacity, as well as glacial and bedrock features. Incompleteness of survey data for certain important properties (e.g., sulphate adsorption capacity, internal proton production, and the role of dry deposition) precludes their use in identifying detailed sensitivities of land or aquatic resources. As far as possible, the eastern parts of the United States and Canada are mapped using a similar conceptual framework which indicates the general extent of areas of different possible sensitivities to the effects of acidic deposition. The significance of these categories will increase as more effects are documented.

189. Rennie, P.J. 1984. Forest resources, air pollution, insects and diseases and other stresses: some relationships. In Rep. 18th Meet., Study Group on Forest Insects and Diseases, North Am. For. Comm., FAO, 29-31 October 1984, Cuernavaca, Mexico. Appendix IV(b). (CFS-HQ)

The forest resources of North America have inestimable social, economic and other values, but today are being subjected to numerous changes. Management systems are becoming more intensive and expectations are increasing, as are pressures and stresses including that of pollution.

In the past, the effects of strong point pollutant emissions have been easy to recognize, but the newer forms of pollution, involving mixtures, acting at lower concentrations, over larger geographical areas and in a more continuous way, are more elusive.

To understand how this newer form of pollution can affect forests, much more needs to be known about the ecological processes underpinning forest growth and how such processes can be changed.

Outward manifestations of stress and change may include nutrient imbalances in the tree tissues or soil, growth disorders and changed proneness to insect and disease attack. Such manifestations can arise from a variety of causes, which may be difficult to separate and assess.

The significance should not be underestimated. The lesson that emerges from the Central European experience is that outwardly the forest continued to grow and nothing much seemed wrong--until large areas of the forest collapsed.

Considering the increasing literature concerned with the effects of pollution on the incidence of forest insects and diseases, and the sensitivities of these organisms to reflect changes in host characteristics, their study warrants increased attention.

For Canada, an Early Warning Monitoring System is being implemented that brings together a number of disciplines for the more comprehensive detection of tree-growth disorders.

190. Rennie, P.J. 1985a. Atmospheric pollution and forest resources: the nature of the threat. For. Ind. Lect. Ser. No. 15, Univ. Alberta, Edmonton, Alta. (CFS-HQ)

The economic, social and environmental values of Canadian forests are widely appreciated, but perhaps not so much the interdependence of forest industry's two main components--the manufacturing and processing enterprise, and the production or growing side. Emphasized are the common elements to both: inputs to secure outputs, trends conditioned by innovation and constraints, and expectations determined by demand and unknown limitations. Dealt with specifically is the threat of air pollution, its not so much imminent appearance in most forest regions, but its potential ability to reduce productivity in unsuspected ways. Tissues can be directly affected and growth processes impaired, soils can be degraded to become less productive, and resistance to insect and disease may be changed through complex interactions that are little understood. Changes to our forest-production systems are taking place. On some 160 million hectares of accessible and commercially productive forest, first-growth natural stands have mostly been converted to second- and third-growth stands of shorter rotation length subject to higher utilization standards. The long-term effects of this increased site demand are mostly unknown. Some 30% of this forest, 7 million hectares in the west and 40 million hectares in the east, are exposed to significant levels of air pollution of inadequately defined composition. Some components--sulphur dioxide--are expected to decrease in the decades ahead, but some--ozone and volatile organics--are not, subjecting both forest tissues and forest soils to stresses of unknown dimensions. Air pollution has already affected soils, but not, as far as is known, coniferous forests. Eastern hardwoods have shown serious dieback, however, thought by some to have been caused or aggravated by air pollution. The challenge facing forest scientists is to develop as full an understanding of their forest ecosystems as is possessed by their colleagues in the companion manufacturing side. Circumstances are changing--air-quality characteristics, soils and forest practices--and rational and reliable guides have to be given to those implementing practices, able to adjust soil fertility levels, or control air quality. Only in this way can the forester guarantee the supplies and fulfil the requirements of the mill engineer.

191. Rennie, P.J. 1985b. Evidence for effects on Canadian forests. Pages 111-122 in Air Pollutant Effects on Forest Ecosystems, 8-9 May, St. Paul, MN. The Acid Rain Foundation. (CFS-HQ)

Except near strong point sources of air pollutants, there are no proven examples of injury to forests caused by regional air pollution. Fifty-five percent of the eastern Canadian forest is exposed to significant levels of acidic deposition, and this causes concern for the continued fertility of the podzolic soils that support the coniferous and mixedwood forests. Some chlorosis is reported, and simulated acid rain experiments suggest tissues may be adversely affected. There is considerable dieback of sugar maple in Quebec and Ontario, the cause of which is debated. The areas are polluted but experience other stresses such as tent-caterpillar epidemics, drought and other exceptional climatic events. In some forests, soil data suggest appreciable loss of nutrients has occurred.

192. Rennie, P.J. 1985c. Future scientific research programs and management approaches. Pages 347-365 in Air Pollutant Effects on Forest Ecosystems, 8-9 May, St. Paul, MN. The Acid Rain Foundation. (CFS-HQ)

The Canadian Forestry Service program in air pollution has expanded from a few scientists concerned with strong point-source problems to a force of some 25 specialists costing $2 million a year. Studies are conducted in all Canadian regions, when the Early Warning System of over 100 permanent sample plots is included, but the main emphasis on process studies is in the appreciably exposed eastern forests. Two main problems exist: first, forests, such as sugar maple or birch, showing serious dieback or foliar loss; secondly, coniferous forests on sensitive terrain which do not yet show obvious injury. Instrumented catchment basins to reveal hydrologic and nutrient budgets are an important Foundation part of the Program, but work on cuticle integrity and rootlet associations using simulated acid rain and associated pollutants is being emphasized to reveal dose/response relationships. Soil work focusing on the speciation and toxicity of aluminum is regarded as especially important in acid soils, while the adequacy of nutrient supplies is taking on greater importance as nutrient supply seems to be inversely related to pollution levels and dieback. Pollutant/pest interactions are to receive more attention as well as those involving pollutants and climate.

193. Rennie, P.J. 1985d. Air pollution and forest resources: the nature of the threat. In Proc. Conf. sobre Aspectos de la Contaminación a los Recursos Forestales, 16-17 May, Secretaria de Agricultura y Recursos Hidraulicos, Subsecretaria Forestal, Mexico City, Mexico. (CFS-HQ)

Forestry today faces increasing challenges--for greater productivity against a shrinking land base, within a context that has not traditionally allowed for the cultural inputs recognized in agriculture and in an environment that has often become seriously polluted.

The situation for Canada is described. Productive forest only covers one-third of the over 900 million hectares and land, and of this only a little over 160 million hectares are economically accessible. Fire and pests deplete this resource, and 55% in the east and 7% in the west are exposed to significant levels of air pollution.

Since 1960 growth of important species in the east has been less than expected, and since 1980 sugar maple has shown serious dieback, the cause of both being unclear. Major abatement programs are being implemented to reduce SO_2 and NO_x emissions, the former by 50% by 1994 (1980 basis) and the latter by 66% on all 1988 and later cars. Substantial research programs are in place, aiming to elucidate air pollutants in need of priority attention and required degrees of abatement. Studies include ongoing monitoring of forest health and process studies designed to quantify dose/response relationships. The latter focus on the direct effects on tissues and indirect effects through soil or via climate and pest epidemic interactions.

194. Rennie, P.J. 1985e. Forestry and pollution. Essay review of 12th Int. Stud. For. Symp., Edinburgh, Scotland. For. Chron. 61:415. (CFS-HQ)

This is an outline of the main papers with perspective remarks on their significance and wider contribution.

195. Rennie, P.J. 1985f. Acid rain. In Minutes of Proceedings and Evidence of the Special Committee on Acid Rain, House of Commons, 17 December. Dep. Supply Serv., Ottawa, Ont. Issue No. 5. (CFS-HQ)

The extent of the Canadian forest is indicated with areas exposed to different types of air pollutants. The five main elements of the CFS research program are described, with explanations of what each can accomplish. Emphasized is the importance of research designed to quantify dose/response relationships, thereby paving the way for scientifically based abatement strategies; and of the Early Warning System comprising over 100 permanent sample plots. Through special monitoring and assessment these can detect the early signs of pollution injury, and they can check on the adequacy of existing abatement measures.

196. Rennie, P.J. 1986a. A review of Canadian investigations (in air pollution). In Proc. 67th Annu. Meet., Can. Pulp Pap. Assoc., Woodlands Sect., Montreal, Que. Sess. 9: Acid deposition and forest health. (CFS-HQ)

Seventy-two percent of Canadian forests appear unexposed to air pollution, but 39 million hectares in eastern Canada and seven million hectares in the far west are significantly exposed. Sulphur dioxide emissions are declining, but ominously not those of nitrogen oxides and hydrocarbons, the precursors of ozone. As safeguards, forest growth and health are being monitored by new techniques, and a variety of process studies are providing dose/response data essential for designing rational abatement strategies.

197. Rennie, P.J. 1987a. The significance of air pollution to forest decline in Canada. Pages 321-334 *in* L. Kairiukstis, S. Nilsson, and A. Straszak, eds. Proc. Workshop on Forest Decline and Reproduction: Regional and Global Consequences, 23-28 March, Int. Inst. Appl. Syst. Anal., Pol. Acad. Sci., Int. Union For. Res. Org., Krakow, Poland. (CFS-HQ)

Forests cover an appreciable proportion of the 909 million hectares of Canada, fulfilling important roles for terrain stability, wildlife support, recreation and flood control. About one-third of this total is potentially commercial forest, the annual harvesting of about 760 000 hectares yielding products valued at $29 billion.

Adverse climate and soils combine to restrict productivity in a generally semi-natural and self-thinning coniferous forest that experiences major losses through fire and pests. Decline and mortality, therefore, are part of the normal scene.

In addition to well-known local pollutant emissions, large forest areas--7 million hectares based on Vancouver Island and the Coast Range, and 39 million hectares in eastern Canada--are exposed to significant regional air pollution, reasonably well documented for acid sulphate and nitrate deposition, but poorly understood for photochemical oxidants, organics and potentially toxic metals.

In principle, concern for forest well-being arises from three pollutant mechanisms--direct damage to tree tissues; indirect and cumulative impairment of soil fertility; and more complex interactions with other stresses such as temperature, drought and pests.

The regular monitoring of Canadian forests by specialists of the Forest Insect and Disease Survey Organization has revealed no discernible effects or decline attributable to regional air pollution in the main coniferous forests. There is, in contrast, a serious dieback epidemic currently affecting sugar maple (*Acer saccharum* Marsh.) in the hardwood and mixed-wood zones of southern Ontario, southern Quebec and New Brunswick. The forests affected are the most polluted in Canada, but stands also experience other stresses--insect attack, exceptional weather patterns, special site features and management demands.

Substantial pollution-abatement measures are being implemented, while research focuses on establishing cause/effect relationships, and on developing appropriate remedial measures. These could be the further abatement of a particular air pollutant and/or field cultural measures enhancing tree resistance or restoring soil fertility.

198. Rennie, P.J. 1987b. Air pollution and the forestry sector: challenges and requirements. In D.P. Lavender, ed. Proc. IUFRO Workshop on Woody Plant Growth in a Changing Physical and Chemical Environment, Univ. British Columbia, Vancouver, B.C. (CFS-HQ)

Although of apparent stability, the Canadian forest environment is undergoing major change. On some 160 million hectares of accessible and commercially productive forest, first-growth natural stands have mostly been converted to second- and third-growth stands of shorter rotation length subject to higher utilization standards. The long-term effects of this increased site demand are mostly unknown. Some 30% of this forest, 7 million hectares in the west and 40 million hectares in the east, are exposed to significant levels of air pollution of inadequately defined composition. Some components--sulphur dioxide--are expected to decrease in the decades ahead, but some --ozone and volatile organics--are not, subjecting both forest tissues and forest soils to stresses of unknown dimensions. Air pollution has already affected soils, but not, as far as is known, coniferous forests. Eastern hardwoods have shown serious dieback, however, thought by some to have been caused or aggravated by air pollution. The challenge facing forest scientists is to develop a fuller understanding of the functioning of their forest ecosystems under conditions of changing atmospheres, forest management and soil. A particular need is to develop dose/response relationships to underpin the air-quality characteristics they must indicate to regulatory authorities to permit sustained forest productivity.

199. Rennie, P.J. 1988a. Excess nitrogen deposition--a Canadian perspective. In Proc. Excess Nitrogen Deposition Workshop. Cent. Electr. Res. Lab., Leatherhead, UK (in press). (CFS-HQ)

The nitrate concentration in precipitation is generally less in eastern Canada (0.6-2.5 mg NO_3 L^{-1}) than in central Europe (>2.2 mg NO_3 L^{-1}), wet deposition rates of nitrate on the coniferous and mixedwood forests of eastern Canada ranging from 10 to 30 kg ha^{-1}. This, taken with the well-known shortage of available nitrogen in northern podzols and the widespread growth responses obtained from fertilizer nitrogen, might give little cause for concern. Other factors, however, must be considered. Almost half the acidity of precipitation in eastern Canada is due to nitrate. Nitrate deposition is tending to increase, whereas sulphate deposition is decreasing. Nitrate is not entirely assimilated by forest growth and contributes via soil percolates to the loss of soil nutrients, to the solubilization of aluminum and increased acidity of lakes. Nitrate deposition cannot be viewed in isolation from NO_x emissions, and the role of the latter as a precursor of both NO_3 and O_3 has to be critically evaluated before an abatement strategy for NO_x can be developed.

200. Rennie, P.J. 1988b. Acidic precipitation: effects on forests. Pages 123-136 in A.S. Lefohn and S.V. Krupa, eds. Proc. APCA Int. Conf. on Acidic Precipitation: A Technical Amplification of NAPAP's Findings, January, Air Pollut. Control Assoc., Pittsburgh, PA. (CFS-HQ)

This paper critically reviews NAPAP's Interim Assessment, specifically the three documents relating to forests: the detailed Chapter 7, its Synopsis, and Executive Summary. Particular attention is focused on the Conclusions, their relation to the science, and their reliability. Amplification is achieved mostly by discussing the adequacy with which topics are developed.

Chapter 7 achieves an outstanding summarization of the very many and diverse studies making up NAPAP's continuing Program, together with the scientific findings of some other programs. Eight case histories of forest decline are examined to discover if acid deposition, SO_2, NO_x, O_3 or H_2O_2 (but not VOCs) alone or in combination are involved. The aim is to provide a scientific base for the formulation of public policy as it pertains to U.S. forests.

In only four of the cases is there proof or strong inference that an air pollutant, ozone, has caused or contributed to decline, but it is suspected of reducing growth in most U.S. forests. Acid deposition or gaseous SO_2 and NO_x at regional concentrations do not appear to impair growth, as judged by direct foliar effects, but experimentation has not advanced sufficiently to tell whether these pollutants could exercise deeper-seated physiological effects, could depress the fertility of certain forest soils, or could interact negatively with natural stresses. In some cases there is evidence, not included in the Assessment, that these mechanisms are operating or that natural stresses predominate.

These important findings, with their constraints, are not expressed clearly in the Executive Summary. Some are lost and other claims are made but not substantiated in Chapter 7. These allay concern to an extent not shared by most scientists. There are disconcerting weaknesses in the scientific logic of Chapter 7 that have pertinence to what studies can and cannot achieve, and one could be apprehensive lest some of the case histories become an end rather than the means toward specifying more widespread air-quality characteristics necessary for sustained forest productivity. However, overall the Interim Assessment establishes a foundation for a much more complex, challenging and time-consuming phase ahead.

201. Rennie, P.J. 1988c. Field tour and catchment-basin approach; Canadian experience. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que., 1983 (in press). (CFS-HQ)

This is an outline of the rationale for including the catchment-basin approach in the Canadian Forestry Service Air Pollution Program. Critically examined are what the approach can and cannot reveal. Characteristics of the three especially selected basins are described.

202. Rennie, P.J. 1988d. Air pollution; its implications for forest productivity. In Forest Climate '86, Symp./Workshop, Orillia, Ont. Can. For. Serv., Atmos. Environ. Serv., Ottawa, Ont., 1986 (in press). (CFS-HQ)

It is widely understood that forests must be protected against fire and pests, but perhaps insufficiently appreciated that continued productivity is dependent upon a particular blend of climatic, air quality, soil and other characteristics.

Air quality over extensive forest regions has become seriously impaired through the emissions of sulphur dioxide, nitrogen oxides, hydrocarbons and potentially toxic metals. Subsequent atmospheric and other in situ reactions have generated a pollutant mix, the significance of which is far from being fully understood.

Adverse effects arise from direct damage to tree tissues, from indirect and cumulative effects on soil fertility, and from more complex interactions with other stresses, such as temperature, drought and pests.

Although substantial pollutant-abatement measures are being implemented, the challenge facing forestry is to develop understanding and guides about required air-quality standards and management practices that will guarantee sustained productivity in a new and changing context. Of particular importance are climatic trends, exceptional climatic events and the climate/air pollutant interaction.

203. Rennie, P.J.; Addison, P.A. 1986. Environmental forestry: a status report on research and development for 1985/86. Can. For. Serv., Res. Tech. Serv. Advis. Rep., Ottawa, Ont. (CFS-HQ)

The state of knowledge on forest decline and growth reductions as they relate to air pollution are presented along with a description of the Canadian Forestry Service LRTAP Program.

204. Rennie, P.J.; Halstead, R.L. 1977. The effects of sulphur on plants in Canada. Pages 69-179 in Sulphur and its inorganic derivatives in the Canadian environment. Associate Committee on Scientific Criteria for Environmental Quality, Natl. Res. Counc. Can., Ottawa, Ont. Publ. No. 15015. 426 p. (CFS-HQ)

Unlike many pollutants, sulphur and its compounds occur naturally and participate in widespread cycling processes that ramify throughout the land, sea, and air. Sulphur is essential for plant and animal life and is present in all vital tissues. Compared with other major nutrient elements it has been neglected; knowledge is lacking on its dynamics in the soil-plant-animal system and on its nutritional and physiological roles in agriculture and forest growth.

Excess amounts of certain sulphur compounds are toxic to plants; high concentrations can arise from both natural and anthropogenic causes. In Canada, some 6.5 x 10^6 metric tons of SO_2 are emitted annually from various man-made activities. This gives cause for concern in three major geographical areas and numerous smaller, more isolated, centres. The major areas are the Sudbury region of Ontario (13.7 x 10^3 km^2), the Windsor-Sudbury-Montreal triangle in Ontario and Quebec (150 x 10^3 km^2), and the Grande Prairie - Edmonton - Pincher Creek triangle in south-western Alberta (78 x 10^3 km^2). The isolated centres include Noranda, Quebec; Thompson, Manitoba; Murdochville, Quebec; and Flin Flon, Manitoba. In these seven areas, the annual SO_2 emissions are estimated to be 2.65, 0.86, 0.43, 0.71, 0.36, 0.17, and 0.12 (all x 10^6) metric tons, respectively.

In one of the major areas--Sudbury--SO_2 emission constitutes a major threat to vegetation and has done so for very many years. In the Windsor-Sudbury-Montreal triangle, the emissions do not constitute a general problem, but the steady industrial-urban expansion there and the proximity of large emissions in Sudbury to the north and in the United States to the southwest, south and southeast warrant a continuing watch on the valuable crops and vegetation of this region. Similarly, the emissions of southwestern Alberta do not yet constitute a general problem, but the agricultural crops of the region are particularly sensitive to SO_2, and the potential for increased emission from sour-gas processing is rising rapidly. Emission from the smaller centres already manifests itself as a series of local problems.

Good estimates for the dimensions of the problem are not available, but overall in Canada it is considered to affect adversely between 1.1 and 2.5 x 10^6 ha, half of which is in the Sudbury region. The overall Canadian area probably comprises 60% forest and 40% agricultural land. Comparison with other statistics--areas affected in Europe and damage to Canadian forest by insect pests--shows the SO_2 problem in Canada to be of major dimensions. The annual direct fiscal loss to the forest alone is thought to lie between \$1.2 and 2.8 x 10^6, quite aside from the unestimated losses arising from the destruction of useful lesser plants and organisms, diminished aesthetic values, and degradation of site fertility.

The problem in the Sudbury region and in the smaller centres arises from the excessive emission of SO_2 derived from smelting or other industrial processes. Long-term monitoring of ambient SO_2 concentrations in the Sudbury region shows that values have repeatedly exceeded those now considered "maximally acceptable" under the Federal Clean Air Act. Concentration values for 1971 do not indicate a major alleviation of the problem, but some improvement is suggested, possibly from the introduction of sulphur-recovery and other technological measures at the smelters.

The solution to the problem lies in reducing emissions to acceptable levels. Various technological and other reasons make this solution more difficult in practice than in theory, especially in the case of general emissions arising from a host of sources in urban-industrial conurbations. But the really difficult underlying problem lies in finding out what are "maximum acceptable" or "maximum desirable" levels. A considerable part of the entire research in pollution has been concerned with this basic problem.

For numerous agricultural and forest plants tested in the Sudbury area, for example, a working approximation suggests that injury is unlikely to occur if fluctuating SO_2 concentrations when averaged do not exceed 2000 $\mu g\ m^{-3}$ over 1 hour, 1140 $\mu g\ m^{-3}$ over 2 hours, 750 $\mu g\ m^{-3}$ over 4 hours and 500 $\mu g\ m^{-3}$ over 8 hours. However, these values are merely working approximations, not guarantees of safety. Lower thresholds are almost certainly necessary for situations where SO_2 acts synergistically with other pollutants, such as ozone or nitrogen oxides. The non-vascular plants--lichens and bryophytes--are more sensitive to SO_2, and concentrations of 30-600 $\mu g\ m^{-3}$ over a long period can completely kill them. Other lesser plants and microorganisms fulfilling essential roles in the growth of higher plants and in the maintenance of soil fertility are also particularly sensitive.

Current Canadian air quality standards allow a certain safety buffer between them and the higher values that are known to cause injury to the higher agricultural and forest plants. For several reasons, the safety buffer is more reassuring in respect of the "maximum desirable" (450 $\mu g\ m^{-3}$ for 1 hour) than the "maximum acceptable" (900 $\mu g\ m^{-3}$ for 1 hour) level. As experience has accumulated over the years for different climatic conditions, threshold concentrations for injury have been revised downward. The additive and synergistic effects of multiple-pollutant mixtures often found in practical situations have also lowered SO_2 thresholds. Important lower plants and microorganisms fulfilling essential roles in the productivity of the more visible plants in ecosystems seem more sensitive to SO_2, but very little has been done with these species and great uncertainty exists. Lastly, exposure to SO_2 has cumulative effects upon perennial plant tissues and soils, which cause progressively greater degradation processes than a currently ambient SO_2 concentration suggests.

Obviously, the standards need to be under continuous review, but there seems to be a particular requirement for increased Canadian research in this area. The various Canadian researchers from different agencies and disciplines need to be in better communication through a permanent Working Group. The dimensions of the problem in various localities need better specification. The results of monitoring studies need wider and better dissemination. Cause/effect investigations need to be initiated in new hazard areas where little is known on the susceptibility of the area's particular plants, and all such impact studies preferably need to have an ecosystem base so that the wider implications of immediate and cumulative effects of SO_2 upon the environment can be assessed. Finally, there is a serious backlog of work to be done on the soil-plant-animal sulphur system by meteorologists, geologists, soil chemists, physiologists, nutritionists, and others so that pollution studies have an effective spring-board from which their results can be intelligently and reliably extrapolated.

205. Rennie, P.J.; Robitaille, G., editors. 1987. Effects of acid rain on forest resources. Proc. Int. Conf., Quebec City, Que. Can. For. Serv., Ottawa, Ont. (CFS-HQ)

These are the proceedings of the conference held in Quebec City on the influence of acid rain on forest systems. The report contains technical papers on most aspects of forest response to acid rain including papers on nutrient cycling, soil and plot effects.

206. Riding, R.T.; Percy, K.E. 1985. Effects of SO_2 and other air pollutants on the morphology of epicuticular waxes on needles of Pinus strobus and Pinus banksiana. New Phytol. 99:555-563. (CFS-M)

Exposure of elongating needles of Pinus strobus L. to SO_2 and other unidentified air pollutants delayed wax deposition in the epistomatal chambers. Following completion of wax deposition, the wax rodlets fused, forming platelike sheets. Needle wettability appeared to be increased as a result of modification of the epicuticular waxes, potentially increasing their sensitivity to acid rain-induced injury. This occurred without alteration of the structure of the stomatal complex itself. No alteration of wax form was evident on needles of P. banksiana Lamb., even under conditions which led to acute SO_2 foliar injury.

207. Roberts, B.A.; Thompson, L.K. 1980. Lichens as indicators of fluoride emission from a phosphorus plant, Long Harbour, Newfoundland, Canada. Can. J. Bot. 58:2218-2228. (NeFC)

Fluoride concentrations in the terrestrial lichens Cladina rangiferina (L.) Harm. and Cladina stellaris (Opiz.) Brodo were correlated inversely with distance from an industrial plant producing elemental phosphorus at Long Harbour, Nfld., in the direction (NE) of the prevailing wind. The fluoride concentrations ranged from 2830 ppm dry weight in a severely damaged area close to the emission source to 15.5 ppm (dry weight) 12 km NE of the industrial plant. Control samples from unpolluted areas had an average fluoride content of 6.4 ppm dry weight. The minimum observed damage symptoms included discolouration and structure loss. Discolouration effects were not as pronounced as observed on Abies balsamea (L.) Mill. or on Polytrichum commune Hedw. but combined with structure loss allowed the degree of damage to be readily identified in the field. Fluoride concentrations in these terrestrial lichens are compared with levels in soil humus, A. balsamea and some terrestrial bryophytes in four damage zones. The lichen tissue had, on average, twice as much fluoride as occurred in soil humus from the same site and about one-half the amount of fluoride found in the terrestrial bryophyte P. commune. The effects of fluoride emissions on the epiphytic lichens Hypogymnia physodes (L.) W. Wats. and Alectoria tosa (Ach.) Ach. in this area are also discussed.

208. Roberts, B.A.; Thompson, L.K.; Sidhu, S.S. 1979. Terrestrial bryophytes as indicators of fluoride emission from a phosphorus plant, Long Harbour, Newfoundland, Canada. Can. J. Bot. 57:1583-1590. (NeFC)

A study of the effects of fluoride emissions (HF, SiF_4) on certain species of bryophytes was carried out in the vicinity of an industrial plant producing elemental phosphorus at Long Harbour, Nfld. Damage symptoms varied from mild phyllid chlorosis (yellowing) to severe browning of up to 95% of the phyllids. Polytrichum commune Hedw. was the main bryophyte species used in the survey. Random collections from 45 sample sites were analyzed for total fluoride. The fluoride concentrations in phyllid tissue ranged from a high of 6066 ppm (dry weight) at a distance of 1 km northeast of the emission source to 44 ppm (dry weight) 11.7 km northeast of the emission source in the direction of the prevailing wind. Control samples were obtained from similar sites in areas far removed from the industrial plant and contained, on average, 11.3 ppm (dry weight). The concentration of fluoride in the bryophyte phyllid tissue was inversely correlated with distance from the emission source, in the direction of the prevailing wind. The severity of acropetal scorching was found to be correlated with the concentration of fluoride in the bryophyte phyllid tissue, and, in addition, samples high in fluoride had fewer sporophytes. Fluoride concentrations in bryophyte tissue are compared with concentrations of fluoride in the needles of balsam fir, Abies balsamea L., in four damage zones, and also with available and total fluoride in soil humus and concentrations of fluoride in air. The total area affected by fluoride emissions was increased by using bryophytes as the pollution indicator species, especially in areas far from the industrial plant.

209. Robitaille, G. 1977. The effects of copper smelter effluents on vegetation. PhD thesis, Univ. Ottawa, Ottawa, Ont. 272 p. (LFC)

The present analysis is a partial description of the environmental impact caused by 20 years of copper smelter emissions from the Gaspé Copper Mine smelter complex at Murdochville, Québec. The pollutants causing the observed impact on some of the biotic and abiotic components of the boreal forest ecosystem were gaseous sulphur dioxide (SO_2) and heavy metals such as Cd, Cu, Pb, and Zn.

The author has documented some of the latest literature on sulphur dioxide effects on lichens and bryophytes and as well has presented a description of the effects of heavy metals on these organisms. A review of the very limited literature on the use of annual rings of trees as a heavy metal monitor and indicator of pollution has also been presented.

The effects of the total pollution load, including both sulphur dioxide and heavy metals, on the epiphytic lichen and moss component of the boreal forest was first evaluated. This was done by producing an Index of Atmospheric Purity (IAP) map which showed the apparent zonation of air quality, that is, gradients of air pollution, based on the sensitivity of epiphytic lichens and mosses to pollutants. Areas close to the smelter had poor air quality (low IAP values), low numbers of epiphytes and low frequency-coverage values. These areas corresponded to high levels of ambient sulphur dioxide concentrations, to high levels of heavy metals in the stemflow of Abies balsamea and to areas of increased acidity of both incident rainwater and stemflow. Heavy metal accumulation by Picea mariana, Clintonia borealis, Hylocomium splendens, Pleurozium schreberi, Hypogymnia physodes and Parmelia squarrosa was greatest in regions closer to the smelter, that is in areas of low IAP, than farther away. In general, both the lichens and mosses accumulated more heavy metals than did the vascular plants.

Epiphytic lichens transplanted from a non-polluted area into areas of heavy, medium, low and background pollution levels reacted predictably to the pollution loads. Decreased thallus adhesion, degree of isidial development, Trebouxia cell size and number of dividing cells and increased numbers of dead and plasmolyzed algal cells occurred in P. squarrosa thalli at increased pollution levels. Spectrophotometric analysis showed that increasing amounts of chlorophyll were lost by algal cells in lichen thalli of both transplanted P. squarrosa and naturally occurring P. squarrosa and H. physodes as pollution concentrations increased.

Acid rain occurred in the study area and this was attributed to an input of sulphur dioxide gas to the atmosphere. This acid rain engendered changes in the epiphyte substratum, that is the bark, such that the buffer capacity of the bark of Abies balsamea increased and decreased respectively; furthermore, a parallel decrease in the pH of the lichen thalli of H. physodes and P. squarrosa was observed. It was suggested that these changes increased the proportion of toxic bisulphite and heavy metal dissolved in the stemflow bathing the lichen thalli and that this contributed to the paucity of epiphytic lichens and mosses in the area close to the copper smelter. The fact that some of the chlorophyll in these epiphytes was converted to phaeophytin and that a sharp decrease in the chlorophyll content also corresponded to an abrupt increase in the heavy metal content in the lichen thalli may support this suggestion.

A method to indicate when the pollution loading started in the study area was also tested. The heavy metal accumulation pattern in the annual rings of A. balsamea was examined as was the variation in the widths of the annual rings. It was noted that increased amounts of heavy metals in the rings corresponded with the year that the smelter operations began. Further, a concomitant decrease in the widths of the rings occurred at the polluted sites. Anomalies in these observations were explained.

It was concluded that the effects of the pollutant input on the biotic and abiotic components studied were real.

210. Robitaille, G. 1979. Pollution and annual rings in Abies balsamea. (Available only in French.) Pages 1-18 in Proc. Conf. Contaminants in the Environment, 14-15 May, Château Frontenac, Quebec City, Que. (LFC)

A controversy exists concerning the potential use of annual rings as indicators of air pollution. The present study was undertaken (a) to attempt to resolve or at least shed light on the controversy, and (b) to document the impact of effluents from a copper smelter located at Murdochville in the Gaspé. Two test sites dominated by Abies balsamea, one polluted and the other unpolluted, were compared. The growth of rings was measured to the nearest tenth of a millimetre. The rings were dated, then analyzed in 5-year groups for Pb, Cu, and Zn. Results indicate an abnormal reduction in diameter growth of Abies, corresponding with the year the smelter opened (1955), and with an increase in content of Pb, Cu, and Zn in the rings. These observations should be confirmed for this species in order to validate the method.

211. Robitaille, G. 1980. Acid precipitation and vegetation. In Proc. 73rd Annu. Meet. Exhib. Air Pollut. Control Assoc., Montreal, Que. Pap. No. 80-24.2. (LFC)

This technical contribution contains one of the very few studies of the heavy-metal contamination of tree rings sampled from a forest surrounding a smelter in the Gaspé, along with a first attempt at ranking and mapping the sensitivity of eastern Canadian forest vegetation.

212. Robitaille, G. 1981. Heavy-metal accumulation in the annual rings of balsam fir Abies balsamea (L.) Mill. Environ. Pollut. (Ser. B) 2: 193-202. (LFC)

The accumulation patterns of Pb, Cu and Zn in annual rings and the growth of balsam fir Abies balsamea (L.) Mill. growing at non-polluted (control) and polluted forest sites are compared. Results show (1) a gradual decrease in metal accumulation from older to younger annual rings at the non-polluted site; (2) this pattern is drastically reversed for the younger rings at the polluted site from the time pollution loading began; and (3) a marked decrease in the growth of annual rings corresponding to the reversal of metal accumulation pattern.

213. Robitaille, G. 1983. Excursion guide, Lac Laflamme Watershed, Montmorency Experimental Forest. In P.J. Rennie and G. Robitaille, eds. Proc. Effects of Acid Rain on Forest Resources, Quebec City, Que. (LFC)

The guide explains the establishment of the Canadian Forestry Service LRTAP project at the Lake Laflamme catchment in the Montmorency Forest in Quebec. A biophysical description of the catchment is given along with the studies related to LRTAP up to 1983. Data on the chemical matrix of incident rain (INC), throughfall (TF), stemflow (SF) and soil solution (SS) are given for 1982. TF and SF are more acid than INC and are enriched in all of the major ions (SO_4, Cl, PO_4, Ca, K, Mg, Mn, Na) except NO_3 and NH_4 which were possibly absorbed by the balsam fir canopy.

214. Robitaille, G.; Boutin, R.; Bernier, B. 1988. Interception chemistry associated with declining sugar maple in the eastern townships, Quebec. Can. J. For. Res. (in press). (LFC)

Sugar maple is declining in the eastern townships of Quebec. The solution chemistry of a maple stand in the early stages of decline (Quebec 1986) was investigated. Incident rain acidity was decreased by the passage through the sugar maple canopy. The throughfall was enriched considerably with cations and anions. Calcium, potassium and magnesium contributed most to the cation surplus. Soil solution was acid. The most abundant cations were Ca and Mg. Nitrate was the prominent anion followed by SO_4. Implications are discussed.

215. Robitaille, G.; LeBlanc, F.; Rao, D.N. 1977. Acid rain: a factor contributing to the paucity of epiphytic cryptogams in the vicinity of a copper smelter. Rev. Bryol. Lichenol. 43:53-66. (LFC)

Based on the present study, we can conclude that the factors determining the sensitivity of an epiphytic community to sulfur dioxide are, in order of importance, the concentration of ambient sulfur dioxide, the pH of water flowing down the trunks, the pH of the bark, the pH of the epiphyte, the buffer capacity of the bark, and the relative percentages of sulfur derivatives (bisulfite ions and sulfuric acid) on and around the thallus. Theoretically, the linkage of all these factors provides a valid basis for a better understanding of the overall effects of sulfur dioxide pollution on epiphytes.

216. Rutherford, G.K.; vanLoon, G.W.; Mortensen, S.F.; Hern, J.A. 1985. Chemical and pedogenetic effects of simulated acid precipitation on two eastern Canadian forest soils. II. Metals. Can. J. For. Res. 15:848-854. (GLFC)

A study to determine the effects of simulated acid rain on two Canadian Shield podzolic soils was performed on field plots and reconstructed profiles. Soils were irrigated with deionized water and HNO_3 and H_2SO_4 (1:2 molar ratio) solutions at pH 3.5 and 2.0. Pore-water concentrations of Na, K, Mg, Ca, Fe, Mn and Al were measured at 15-60 cm over 2 years. Half the reconstructed profiles were dismantled after 1 year. Total organic C, exchange cations Ca, Mg, K, and Na, and titratable acidity were measured and three different extraction procedures were used to determine soil-free iron and aluminum oxides. Al mobilization high in the profile, with extreme values up to 40 mg L^{-1} at pH 2.0, was followed by redeposition lower in the profile. Up to threefold enhancement of Ca and Al leaching was observed under the most acidic conditions, particularly in the field. Evidence in the present study suggests that anion affinity of the mineral soil reduces the leaching of base cations. A significant decrease in free iron oxides just below the Ae horizon was observed in one of the soils.

217. Salonius, P.O.; Fisher, R.A.; Mahendrappa, M.K. 1982. An alternative method of measuring fertilizer effects in forest stands. Can. J. For. Res. 12:146-150. (CFS-M)

In natural stands, variations in growth rates between plots before treatment due to variable stocking, variable population structure, and site differences often preclude the assessment of growth response to fertilizer treatment by conventional plot comparison. An alternative methodology is described, using growth for a black spruce stand in a pretreatment period as the standard against which growth following treatment is compared for each tree. The results of this comparison on treated and control plots are then related to each other to evaluate growth response to fertilizer treatment. Methods for extracting meaningful fertilizer response data are suggested for experiments which are in progress or are completed but not yet harvested.

218. Salonius, P.O.; Mahendrappa, M.K. 1979. Respiration and nitrogen immobilization in forest soil treated with sulfur and urea. Soil Sci. 127:358-364. (CFS-M)

Respiration and nitrogen immobilization of the fresh organic layer of an acid podzol were studied, after pretreatment with sulfur treatment of microsites when sulfur-coated urea is applied to the soil. The laboratory incubations were done at 10 and 20°C with several levels of urea application. Urea hydrolysis was slowed down considerably at 10°C in materials that had been pretreated with sulfur. Sulfur pretreatment modified the increase in pH and respiration caused by urea application but had little influence on the availability of ammonium nitrogen. The lower temperature allowed adequate fertilizer nitrogen recovery from moderate dosage rates that produced a pH lower than neutrality. At the higher temperature, fertilizer nitrogen recoveries were very poor. At higher pH, a large part of the immobilization of nitrogen appears to be nonmicrobial.

219. Samoil, J.; Turdle, G., editors. 1984. Toxic substances and the forest environment. Can. For. Serv. For. Rep. 30. (NoFC)

This is a popularized report on the studies carried out at Northern Forest Research Centre. The report is a collection of papers by several authors on a variety of topics such as: Toxic substances and the forest environment (P.A. Addison), Elemental sulfur affects plants (K.A. Kennedy), Acid rain can damage forest systems (G.D. Hogan), Biomonitoring of air pollution impacts in the Athabasca Oil Sands forests (P.A. Addison), Changes in soil chemistry influence forest productivity (D.G. Maynard), Natural radionuclides part of the environment (M.J. Apps), Metal particulate emissions affect forest systems (G.D. Hogan), and Biochemistry and physiology used in air pollution research (S.J. L'Hirondelle).

220. Sarkar, S.K.; Malhotra, S.S. 1979a. Gas liquid chromatographic separation of common amino acids in pine needle extracts. J. Chromatogr. 170:371-378. (NoFC)

An improved gas-liquid chromatographic method based on the separation of N-trifluoroacetyl n-butyl esters of amino acids on a "two-column" setup--Tabsorb and Tabsorb HAC--was developed for the identification and estimation of amino acids in pine needles (Pinus banksiana Lamb.). A comparative study was made of various available gas-liquid chromatographic methods for separation and estimation of amino acids from pine needle extracts.

221. Sarkar, S.K.; Malhotra, S.S. 1979b. Gas liquid chromatographic method for separation of organic acids and its application to pine needle extracts. J. Chromatogr. 171: 227-232. (NoFC)

A gas liquid chromatographic method for the separation of a mixture of twenty organic acids is described. A column packed with Gas-Chrom Q (100-120 mesh) coated with 4% XE-60 was employed. Both TCA cycle acids as well as a number of important non-TCA cycle acids were separated satisfactorily with this column. Pine needle organic acids were separated and identified with this column. Quinic and shikimic acids accounted for over 60% of the total peak area.

222. Sarkar, S.K.; Malhotra, S.S. 1979c. Effects of SO_2 on organic acid content and malate dehydrogenase activity in jack pine needles. Biochem. Physiol. Pflanzen 174:438-445. (NoFC)

Sulfur dioxide fumigation (0.34 ppm for 96 h and 0.51 ppm for 72 h) of young jack pine (Pinus banksiana Lamb.) seedlings produced needle tip burning and caused a reduction in their organic acid content. Quinic acid, the major component, declined under both concentrations, whereas shikimic acid, second to quinic acid in abundance, declined under 0.51 ppm exposure but remained unchanged at 0.34 ppm exposure. Syringic acid increased at both SO_2 concentration levels, but the increase was lower at 0.51 ppm than at 0.34 ppm. Malic acid dehydrogenase activity declined long before the development of visual symptoms of SO_2 toxicity. The enzyme activity was reduced to almost 50% of the control value after 92 h fumigation with 0.34 ppm SO_2, at which point the visual symptoms began to appear. The malate dehydrogenase assay appears to have potential as a tool to detect SO_2 injury to vegetation prior to visual symptom development.

223. Sidhu, S.S. 1977. Fluoride levels in air, vegetation and soil in the vicinity of a phosphorus plant. In Proc. 70th Annu. Meet. Air Pollut. Control Assoc., June, Toronto, Ont. Pap. No. 77-30.2. (NeFC)

The information in this paper is related to results of 20 weeks of monitoring of air, vegetation and soil for fluoride in the vicinity of a phosphorus plant. Circular Na-formate enriched filter papers were used to monitor fluoride concentrations in air. The data from Na-formate papers compared significantly with that from sequential samplers. A regression equation ($Y = 17.04 + 5.39 X$) was established for g F dm^{-2} wk^{-1} and g F m^{-3}. This equation resulted in g F m^{-3} values which were 20% higher than those obtained by Adam's equation ($Y = 4.36 X$). The g F m^{-3} in air ranged from 0.82 to 20.78 at 0.7 km and 0.06 to 0.34 at 18.7 km from the source. F-concentrations in vegetation and soil were significantly correlated to the air concentrations. The present data indicate that safe levels of fluoride in air for forest species is 0.23 g F m^{-3}. The forest vegetation in the Long Harbour area did not exhibit any serious damage when the F-concentrations in air exceeded 0.55 g F m^{-3} 20% of the time and 0.20 g F m^{-3} 60% of the time during a single growing season.

224. Sidhu, S.S. 1978a. An improved equation for the estimation of ambient fluoride concentrations from fluoridation plates data. Bi-mon. Res. Notes, Can. For. Serv. 35:10-11. (NeFC)

A revised equation $Y = 5.54 X$ to convert the fluoridation plates data to µg F m^{-3} was proposed in this paper.

225. Sidhu, S.S. 1978b. Patterns of fluoride accumulation in forest species as related to symptoms and defoliation. In Proc. 71st Annu. Meet. Air Pollut. Control Assoc., June, Houston, TX. Pap. No. 78-24.7. (NeFC)

Results of four years of study are presented in this paper. The following conclusions are listed:

a) Typical fluoride-injury symptoms developed on a number of forest species as chlorotic to burned tips in 3-5 weeks after bud break. The progression of symptoms was complete by the end of the 2nd growing season in conifers (e.g. balsam fir, black and white spruce) and by leaf fall in broadleaf species (e.g. white birch, American ash, alder). Defoliation set in after the 35 ppm F-accumulation in the foliage.

b) Threshold levels (to first F-symptoms appearance) of F-accumulation were different among species and at different air concentrations. These levels were highest in severely damaged areas and lowest in lightly damaged areas.

c) Threshold levels of F-concentration in air were 0.20 µg F m^{-3} for the conifers and 0.40 µg F m^{-3} for the deciduous broadleaf species.

d) Fifty percent of F-accumulation for the first year of exposure took place during the first 5-6 weeks of exposure and 90% of the maximum F-accumulation in conifers was attained by the fall of the 2nd year of exposure. In deciduous species a new cycle of F-accumulation set in every spring, and the accumulations in deciduous species during the 1st year of exposure were 1.5 to 4 times those in conifers.

e) Defoliation in evergreens set in at an accumulation level of 35 ppm and reached >70% at an accumulation level of 350-400 ppm.

f) The 0.20 µg HF m^{-3} (or 0.19 µg F m^{-3}) level may be adopted as a Canadian Air Quality Standard for a continuous exposure period of 70 or more days. The level is safe from the point of view of visible injuries, as well as accumulation levels of <35 ppm in foliage over 2 years of exposure.

226. Sidhu, S.S. 1978c. Fluoride in berries from fluoride contaminated and control areas. Can. For. Serv. Inf. Rep. N-X-164. 15 p. (NeFC)

Fluoride concentrations in berries and foliage of bakeapple, blueberry, crackerberry, chuckley pear, crowberry, partridgeberry, raspberry and skunk currants from fluoride contaminated and control areas are reported. Fluoride concentrations in berries from contaminated areas varied from 4.0 ppm in partridgeberry to 106.2 ppm in raspberry. Corresponding foliar F-concentrations were 14.1 and 990.1 ppm. F-concentrations in the same species depended on the location of sample sites in relation to the source. F-concentrations in berries from control areas ranged from 1.9 ppm in partridgeberry to 11.7 ppm in crackerberry. Corresponding foliar concentrations were 8.1 and 14.8 ppm. The significance of ingestion of additional quantities of fluoride by humans is discussed and it does not appear to be a cause of concern at this time.

227. Sidhu, S.S. 1979. Fluoride levels in air, vegetation and soil in the vicinity of a phosphorus plant. J. Air Pollut. Control Assoc. 29:1069-1072. (NeFC)

The concentrations of fluoride in the air, vegetation and soil of a forested ecosystem were monitored over a period of 20 weeks. Boreal vegetation did not experience any serious damage to foliage in areas where atmospheric fluoride concentrations were 0.17 to 0.23 µg F m^{-3}. The results show that if F-emissions are maintained at proposed National Standards there will be little visible damage to vegetation in the Long Harbour area.

228. Sidhu, S.S. 1980. Patterns of fluoride accumulation in boreal forest species under perennial exposure to emissions from a phosphorus plant. In M.M. Benarie, ed. Atmospheric Pollution 1980, Proc. 14th Int. Colloq., Paris, France. Stud. Environ. Sci. 8:425-432. (NeFC)

The information in this paper relates to accumulation patterns of fluoride (f) in foliage of boreal forest species under perennial exposure to emissions from a phosphorus plant. Regressional relationships of foliar F-levels to long-term average F-concentrations in air are also presented. These relationships are used to predict F-levels in air corresponding to foliar F-accumulations which are considered safe for the health of plants and consuming animals.

Accumulation of fluoride in balsam fir and other boreal conifers reached its maximum at the end of the second year of exposure, and foliar F-levels stabilized thereafter. Patterns and levels of F-accumulation in other boreal conifers were similar to those in balsam fir. A regression equation, $Y = 1.89 X - 1.41$, was derived to express the relationship of F-levels in foliage exposed for 1 year (X) to those in foliage exposed for 2 years (Y). This doubling of foliar F-levels in 2 years is important to be considered for establishing air quality standards safe for the health of plants and consuming animals. An air concentration of 37.4 $\mu g\ F\ dm^{-2}\ wk^{-1}$ (= 0.29 $\mu g\ F\ m^{-3}$) is predicted to result in 20 ppm of F-levels in foliage, reported to be a safe level for plants and consuming animals. This F-level in air compares reasonably well with the recommended Canadian standard of 0.20 $\mu g\ HF\ m^{-3}$ average for a 70-day exposure period and 0.30 $\mu g\ HF\ m^{-3}$ average recommended by IUFRO for a 1-year period.

229. Sidhu, S.S. 1981. Results of air monitoring from 1976 to 1980 in the vicinity of a phosphorus plant, Long Harbour, Newfoundland. Can. For. Serv. Inf. Rep. N-X-203. 55 p. (NeFC)

Results of a 5-year (1976 to 1980) air monitoring program for fluorides in the vicinity of a phosphorus plant, Long Harbour, Newfoundland, are presented in this report. Seasonal and annual fluxes of gaseous fluorides in the air were monitored weekly by a static method using Naformate filter papers. The F-concentrations in air were correlated with the development of F-damage symptoms and F-accumulations in foliage of boreal species. Important correlations are highlighted in this report.

Since 1976 there has been a 54-87% decrease in the F-concentrations in the air, most of the decrease occurring in 1980. Regression equations for distance from emission source and F-air concentrations were established for each year. Threshold levels for the development of visual F-damage symptoms on foliage were established to be 0.20 $\mu g\ F\ m^{-3}$ and 0.40 $\mu g\ F\ m^{-3}$ for boreal conifers and broadleaved deciduous species respectively. Pattern of F-accumulation in conifers suggested that accumulations reached their maximum at the end of the second growing season under perennial exposure. Accumulations of 20 and 35 ppm of fluoride in foliage (considered to be safe for animal consumption) were predicted to result in average (2 years' exposure) air concentrations of 0.29 μg F m^{-3} and 0.46 μg F m^{-3} respectively. At these levels very light or no visual F-damage symptoms occurred on conifers and broadleaved species in the region. The safe level 0.29 μg F m^{-3} is very similar to 0.30 μg HF m^{-3} recommended by IUFRO for a 1-year exposure. At an average F-concentration of 0.29 μg F m^{-3} in air and accumulation levels of 20 ppm in vegetation, probably the fluoride levels in urine would remain at 10 ppm. Ten ppm was reported to be safe in cattle by Israel (1974).

230. Sidhu, S.S. 1982a. Fluoride deposition through precipitation and leaf litter in a boreal forest in the vicinity of a phosphorus plant. Sci. Total Environ. 23:205-214. (NeFC)

Results of short-term monitoring of fluoride (F) deposition in soil humus through precipitation and leaf litter in a boreal forest in the vicinity of a phosphorus plant are described in this paper. Regressional relationships of F-deposition by the two pathways to the distance from the emission source are also presented.

The concentrations of fluoride in leaf litter of several species and precipitation and P, Ca, Mg, K and Na in precipitation only are summarized. The average F-concentrations ranged from 930 to 17 ppm in severely and lightly damaged areas respectively. Corresponding F-concentrations in precipitation were 0.36 to <0.01 ppm. Fluoride deposition in soil humus via precipitation was at least 5 times greater than through leaf litter. F-input through precipitation ranged from 3.43 to 0.15 kg ha^{-1} yr^{-1} in areas of severe to light F-damage respectively. Corresponding values from leaf litter were 0.72 to 0.010 kg F ha^{-1} yr^{-1}.

Estimates of total and available amounts of fluoride in the upper 4 cm of soil humus were 57.0 to 1.20 kg ha^{-1} and 1.20 to 0.24 kg ha^{-1} in areas of severe and light damage respectively. The excessive concentrations of fluoride in soil humus did not appear to contribute towards the F-accumulation in foliage.

231. Sidhu, S.S. 1982b. Effects of simulated acid rain on pollen germination and pollen tube growth of white spruce (*Picea glauca* (Moench) Voss). Can. J. Bot. 61:3095-3099. (NeFC)

The effects of simulated rain of pH 2.6 to 5.6 on pollen germination and pollen tube growth were studied in white spruce (*Picea glauca* (Moench) Voss) under three temperature regimes.

Results indicate that little or no adverse effects were produced on germination and pollen tube growth by acid rain of pH above 3.6 during release or germination. However, rain of equal to or less than pH 3.6 reduced germination by up to 30% in pollen washed with acid rain and germinated on normal agar medium. Germination was reduced further and pollen tube growth strongly inhibited in pollen germinated on agar medium prepared with acid rain of equal to or less than pH 3.6.

232. Sidhu, S.S. 1985. Results of air and vegetation monitoring from 1981 to 1985 in the vicinity of a phosphorus plant, Long Harbour, Newfoundland. Can. For. Serv. Inf. Rep. N-X-230. 23 p. (NeFC)

Results of a 3-year (1981 to 1983) air and vegetation monitoring program for fluorides in the vicinity of a phosphorus plant, Long Harbour, Newfoundland, are presented in this report. Seasonal and annual fluxes of gaseous fluorides in the air were monitored weekly by a static method using Na-formate filter papers. The F-accumulations in air were correlated with the F-accumulations in foliage of balsam fir and alder. The results are assessed in terms of the Provincial Air Pollution Control Regulations.

Since 1980, the weekly F-deposition on fluoridation plates varied widely, e.g. 29.62 to 422.79 $\mu g\ F\ dm^{-2}\ wk^{-1}$ in 1983. There was an increase in the F-concentrations in air from 1980 to 1981 and 1982. However, there was a drop of 13 to 70% in 1983, mostly due to lower F-levels during August 1983. The F-accumulation in balsam fir and alder foliage correlated well with the F-levels in air. During the monitoring periods in 1981 to 1983, provincial fluoride vegetation and air standards were probably not met up to a NE-distance of 5.8 to 8.0 km from the source.

233. Sidhu, S.S.; Roberts, B.A. 1976. Progression of fluoride damage to vegetation from 1973 to 1975 in the vicinity of a phosphorus plant. Bi-mon. Res. Notes, Can. For. Serv. 32:29-31. (NeFC)

Progression of fluoride damage to forest vegetation for three consecutive years was described and related to the F-accumulation levels in the foliage of dominant tree species. The levels of fluorides in soil humus were presented for areas of varying degrees of fluoride damage.

234. Sidhu, S.S.; Singh, P. 1977. Foliar sulfur content and related damage to forest vegetation near a linerboard mill in Newfoundland. Plant Dis. Rep. 61:7-11. (NeFC)

A survey for sulfur dioxide damage in the vicinity of a linerboard mill revealed that most damage was restricted within 0.8 km of the source. The damage to balsam fir, black spruce, white birch, red maple and speckled alder was related to increase (48% to 157% of the control) in the total sulfur content of the foliage.

The incidence and intensity of the damage varied between species and between sites. The "Species Damage Index" (SDI) and "Composite Site Damage Index" (CSDI) are proposed to quantify the impact of the pollutant. The SDI has been used to determine the relative sensitivity of species to the pollutant. A significant correlation ($r = 0.99$) has also been established between the CSDI and % difference between the sulfur content of the damaged and undamaged foliage.

235. Sidhu, S.S.; Staniforth, R.J. 1986. Effects of atmospheric fluorides on foliage and cone and seed production in balsam fir, black spruce and larch. Can. J. Bot. 64:923-931. (NeFC)

Fluoride accumulations and damage symptoms to foliage, cones, and seeds of balsam fir (Abies balsamea (L.) Mill.), black spruce (Picea mariana (Mill.) B.S.P.), and larch (Larix laricina (Du Roi) K. Koch) were monitored at six sites downwind from a phosphorus plant that emitted fluorides during 1982. Atmospheric fluoridation rates ranged from 347.4 μg F dm^{-2} wk^{-1} (11.38 μg F m^{-3}) at 1.4 km from the fluoride source to 2.5 μg F dm^{-2} wk^{-1} (0.08 μg F m^{-3}) at 18.7 km. Various degrees of foliar damage (chlorosis, necrosis, needle damage, and defoliation) occurred where fluoride accumulations in the foliage exceeded 20 ppm. This occurred at sites where the fluoridation rates were in excess of 26.0 μg F dm^{-2} wk^{-1}, and at distances less than 10.3 km downwind from the fluoride source. Reductions in seed size, percent germination, number of seeds per cone, number of cones per tree, number of fertile trees, and size reduction, distortion, or mortality of the cones occurred under the same fluoridation rates. Seed output on the windward sides of trees was significantly less than that on the leeward sides. At the most polluted site, seed production in balsam fir, black spruce, and larch, respectively, was reduced to 3.6, 2.6, and 0.0% of that at a control site. All three species in the study are considered to be susceptible to fluoride damage, with respect to both vegetative and reproductive symptoms. Reproductive failure and past mortality of fluoride-damaged conifers have resulted in their replacement by more tolerant hardwood species (e.g., birch (Betula papyrifera Marsh.), alder (Alnus crispa (Ait.) Pursh)) as the dominant forest species in the vicinity of the phosphorus plant.

236. Sidhu, S.S.; Zakrevsky, J.G. 1982. A standardized method for determining buffering capacity of plant foliage. Plant Soil 66:173-179. (NeFC)

A method for determining the buffering capacity (B.C.) of foliage extracts was standardized and evaluated. Sources of variations (biological, field and laboratory) were identified. These variations were reflected in inter-specific differences, seasonal fluctuations, age of the foliage and duration and the conditions of storage of the extracts. Procedures have been recommended to eliminate or minimize sources of variations (other than inherent specific) by standardizing the field sampling, laboratory processing and methods, and calculations of the buffering capacity. Plants such as lichens, known to be sensitive to air pollutants, had very low B.C. whereas species of intermediate sensitivity such as balsam fir had higher B.C. The B.C., being inherited and significantly different among species, has potential for its use in indexing the relative sensitivity of species to air pollutants especially in areas where large numbers of species are to be compared.

237. Singh, T.; Kalra, Y.P. 1977. Estimation of natural pollution loads from streamflow measurements in remote catchments. Water Air Soil Pollut. 7:111-116. (NoFC)

In a study conducted in Marmot Creek Basin (total area 9.40 km^2) situated in the Rocky Mountains of Alberta, equations were developed to obtain gross estimates of the total inorganic solutes dislodged from three forest catchments on a monthly and annual basis. The r^2 range of the equations was 99% or greater, indicating excellent fit in all cases. The equations are suitable for in situ estimation of the pollution loads directly from streamflow measurements, especially for remote catchments.

238. Singh, T.; Kalra, Y.P. 1984. Predicting solute yields in the natural waters of a subalpine system in Alberta, Canada. Arct. Alp. Res. 16:217-224. (NoFC)

An intensive sampling of the natural waters originating from a subalpine watershed was carried out during 1971 and 1972. The information obtained was utilized in regression models to estimate daily outputs of the main constituents (Ca^{2+}, Mg^{2+}, and HCO_3^-) and other constituents (Na^+, SO_4^{2-}, and SiO_2). Despite the small size of the area (9.40 km^2), the yields of the geochemical constituents were large; the sum of constituents ranged from 12.4 to 409.2 t km^{-2} yr^{-1}. The derived equations were independently tested for their predictions for the years 1973 and 1974, and showed their validity in such estimations. The statistical relationships for estimating solute loads provided geochemical information on the subalpine system for different times during the year. The rate of increase in solute yields for unit increase in streamflow was maximum for HCO_3^- and Ca^{2+}, moderate for SO_4^{2-} and Mg^{2+}, and minimum for SiO_2, Na^+, and K^+. Maximum solute loads were transported during the months having maximum streamflows (May, June, July).

239. Skorepa, A.C.; Vitt, D.H. 1976. A quantitative study of epiphytic lichen vegetation in relation to SO_2 pollution in western Alberta. Can. For. Serv. Inf. Rep. NOR-X-161. (NoFC)

Lichens were studied on Pinus contorta var. latifolia around two recent sources of SO_2 pollution in the Rocky Mountain House area of west-central Alberta, Canada. A relative luxuriance-density index was developed to detect changes in the epiphytic lichen flora in an area where a lichen desert had not yet developed. The luxuriance-density values were more sensitive than the Index of Atmospheric Purity in illustrating recent changes in the flora. Analysis of the data by ordination and cluster analysis techniques distinguished four epiphytic lichen associations, three of them affected by the SO_2 pollution. After three years of exposure to the SO_2 pollution, the adjacent lichen flora has been greatly affected. Alectoria glabra, Cetraria halei, and Usnea alpina, all common components of the unaffected vegetation, are among the more sensitive species.

240. Staniforth, R.J.; Sidhu, S.S. 1984. Effects of atmospheric fluoride on foliage, flower, fruit, and seed production in wild raspberry and blueberry. Can. J. Bot. 62:2827-2834. (NeFC)

Reproductive and vegetative characteristics of raspberry and blueberry plants were monitored at six sites downwind from a phosphorus plant which emitted gaseous and particulate fluorides. Atmospheric fluoridation rates ranged from an average of 347.4 $\mu g\ F\ dm^{-2}\ wk^{-1}$ (or 11.38 $\mu g\ F\ m^{-3}$) at 1.4 km to 2.5 $\mu g\ F\ dm^{-2}\ wk^{-1}$ (or 0.08 $\mu g\ F\ m^{-3}$) at 18.7 km from the source. The highest fluoridation levels were in July, the month in which flowering in the two species reached its peak. At the most polluted site, flower mortality was 89% for blueberry and 78% for raspberry; this accounted for most of the loss in reproductive potential. Comparative values of the control site (18.7 km from source) were 27 and 26%, respectively. There were 21- and 10-fold decreases in seed production per plant in blueberry and raspberry, respectively, as well as significant decreases in the size, number, and dry weight of fruit. Fluoride damage to blueberry plants did not result in any effects being passed on to seedlings, except for a slightly accelerated germination rate. Fluoride accumulations in the foliage of plants 1.4 m from the source were 403 ppm for raspberry and 216 ppm for blueberry but only 8 and 9 ppm, respectively, at the control site. Fluoride-affected raspberry plants also showed foliar injury, enhanced vegetative spread, and delayed leaf fall in the autumn.

241. Tardif, M.L. 1985. Effects of acidified water on colonization of roots of Abies balsamea (L.) Mill. seedlings in situ by ectomycorrhizae. (Available only in French.) CFS contract. (LFC)

Balsam fir seedlings (Abies balsamea (L.) Mill.) growing in a woodland were treated with acidified water 11 times to determine the effect of the treatments on the growth of plants and on their ectomycorrhizae.

In the field, plantlets were sprayed weekly with acidified water at pH 2.5, 3.0, 3.5, and 4.0. The control seedlings received only rainwater at pH 4.8.

The treatments caused a significant reduction in the number of mycorrhizae, the number of long roots per seedling and the health of the above-ground portion, proportional to the degree of acidity.

These results suggest that mycorrhizae are very sensitive to disturbances in the soil and/or to the weakening of a plant's above-ground parts.

However, they do not allow us to determine the direct or indirect effects on the ectomycorrhizae caused by damage to the above-ground parts of plants.

242. Thacker, D.J.; Rutherford, G.K.; vanLoon, G.W. 1987. The effects of simulated acid precipitation in the surface horizons of two eastern Canadian forest Podzol soils. Can. J. For. Res. 17:1138-1143. (GLFC)

Undisturbed 18-cm soil cores of the L, F, H, Ae, and upper Bhf horizons of Ferro-Humic Podzols from the Turkey Lake Watershed (Ontario) and Montmorency Forest (Quebec) were treated in the laboratory with 10 m of simulated acid precipitation at pH 5.7, 3.5 and 2.0 over approximately one year. Leachate samples were collected from the bottom of the humus layer and the bottom of the soil core and the soils were analyzed at the completion of leaching. The soils from the two sites behaved similarly. Anion concentrations in the leachates adjusted to input levels after approximately 2 m of simulated rainfall. Leaching generally produced an initial flush of cations followed by lower concentrations. The pH 2.0 treatment caused major changes in some soil properties; the pH 3.5 and 5.7 treatment had a more modest effect.

Base saturation was markedly reduced following the pH 2.0 treatment, slightly reduced following the pH 3.5 treatment and slightly increased following the distilled water treatment. Cation exchange capacity was reduced only in the organic horizons receiving pH 2.0 treatment. Organic C, total N, and C/N ratios showed no changes on acidification. Leaching of Fe and Al was only substantial with the pH 2.0 treatment, and much more Al than Fe was mobilized. Bicarbonate-extractable P in the mineral soil was doubled by the pH 2.0 treatment compared to the other treatments. X-ray diffraction of clays indicated a loss of hydroxy-Al interlayers with increasing acidity which is a stage in the acidic transformation of micaceous to smectite-like materials in Podzolic soils.

243. Thompson, L.K.; Sidhu, S.S.; Roberts, B.A. 1979. Fluoride accumulations in soil and vegetation in the vicinity of a phosphorus plant. Environ. Pollut. (Ser. B) 18:221-234. (NeFC)

This paper presents the results of three consecutive annual surveys for total damage area, severity of damage, symptomatology, accumulation levels of fluoride in plants and soils and isopol maps of fluoride concentrations in plant and soil.

244. Ung, C.-H.; Bertrand, F. 1987. A qualitative analysis of the differential equations for a sugar maple growth model. Can. J. For. Res. 17:588-593. (LFC)

This paper describes a forest growth model based on the Weibull function. An estimation of the model parameters is made using data from 89 permanent sample plots of the Quebec Ministry of Energy and Resources. Sugar maples occupy more than 75% of the total land area in each plot. Qualitative analysis is used in a comprehensive study of the mathematical operation of the model.

245. vanLoon, G.W.; Hay, G.W.; Goh, R.H.T. 1987. Analysis of sulfur-containing components of a soil treated with simulated acid rain. Water Air Soil Pollut. 34:233-240. (GLFC)

Samples of the LFH and Bfh horizons of an Orthic Humo-Ferric Podzol were analyzed for S components after irrigation with simulated acid rain solutions of pH 5.7, 3.5, and 2.0 for 720 days. Organic S was preponderant. In the LFH horizon, the mass ratio of ester sulfate: carbon-bonded S was approximately 1:1 for samples treated with solutions of pH 5.7 and 3.5; for the sample treated with the pH 2.0 solution, the ratio was about 2:1 and the concentrations of both inorganic sulfate and ester sulfate were markedly higher. In the Bfh horizon, carbon-bonded S was the major form of organic S, except in the sample subjected to the high-acid (pH 2.0) simulated rain. The organic S components were further separated into chloroform-soluble, aqueous trifluoracetic acid-soluble, and residual fractions. Significant increases in inorganic sulfate, both water soluble and adsorbed, were found after the pH 2.0 treatment.

246. Vigneault, Y.; Robitaille, G. 1982. Effects of acid rain on aquatic and terrestrial ecosystems. In Proc. Que. Biol. Assoc. Congr. 1982. 15 p. (LFC)

This paper contains a general discussion on the effects of acid precipitation on aquatic and terrestrial ecosystems. Maps are presented that show aquatic and terrain sensitivity of Quebec landscapes. Soil acidification is discussed in relation to boreal fir forest ecosystems. The Lake Laflamme project of the Canadian Forestry Service is presented.

247. Visser, S. 1984. Microbial activity and biomass in the forest floor of a lodgepole pine stand polluted with sulfur dust. Univ. Calgary rep. to Can. For. Serv., Edmonton, Alta. (NoFC)

A study was conducted to determine the effects of sulfur dust pollution on pH, microbial respiration, microbial biomass C, glucose mineralization patterns and selected soil chemical characteristics in the organic mat and mineral soil in a lodgepole pine stand near Rocky Mountain House, Alberta. In the organic soil, oxidation of the S dust which had accumulated over a period of four years significantly reduced the pH, microbial biomass C, and total Ca, Mg, K, Mn, and P levels, particularly within 150 m of the blocks. Glucose mineralization patterns were altered as a result of acidification, whereas soil respiration remained relatively unaltered. Microbial biomass C was more highly correlated with pH than soil S concentration. Although the 0-10 cm deep mineral soil demonstrated a decreasing trend in pH with increasing S levels, no significant effects on soil respiration and microbial biomass C were detected.

248. Walker, S.L.; Auclair, A.N.D. 1988. The distribution of forest declines in Western Canada and adjacent areas of the United States. Federal LRTAP Liaison Office, Atmos. Environ. Serv., February. (CFS-HQ)

This paper represents a very preliminary account of forest declines in western Canada and adjacent areas of the United States. The forest declines in western Canada are not well known or recognized as part of the larger complement of regions and tree species showing decline problems. In order to establish a common basis for comparison and discussion of symptoms, development, and causes, we have adhered to the definition of forest decline characteristics enumerated by Paul Manion (1981) and David Houston (1981).

The purpose of this paper is to document the temporal occurrence and geographic distribution of forest declines in western Canada. We seek to identify causes of forest decline defined within specific symptom and development characteristics. As part of the study, therefore, we will assess whether the declines fit the classical Manion-Houston definition and compare decline characteristics to establish commonalities or differences among species.

249. Whitney, R.D.; Ip., D.W. 1988. Effects of simulated acid rain on field grown Abies balsamea (L.) Mill. in Ontario. I. A system for applying simulated acid rain to field grown saplings. Eur. J. Pathol. (in press). (GLFC)

A shelter was designed to exclude natural precipitation from 1- to 2-metre-high, naturally occurring saplings, while applying simulated acid rain (SAR). Pyramid-shaped, ventilated plastic shelters were built over 60 balsam fir (Abies balsamea (L.) Mill.) saplings under a mixed-wood canopy. The shelter size was expected to accommodate 2 additional years' growth. Measurements of relative humidity, temperature, and light intensity inside the shelters showed that conditions were maintained within acceptable limits with respect to the immediate environment. Three pH treatments of SAR were prepared in the field (c. 5500 L) every 2 weeks and applied to the trees using a portable mixing and watering system. The system worked very well in the present study, despite highly variable topography and tree density. The amount of work involved and problems peculiar to the field aspect are detailed.

250. Wickware, G.M.; Cowell, D.W. 1985. Forest ecosystem classification on the Turkey Lakes Watershed, Ontario. Ecol. Land Class. Ser. No. 18, Environ. Can. (GLFC)

This study set out to define the biophysical conditions and ecological relationships in the Turkey Lakes Watershed in terms of their existing vegetation, soil and site characteristics. This information is to provide baseline data for further research and to improve our understanding of the complex interactions between incident acid precipitation and various components of the forest ecosystem. The results, obtained through intensive field sampling and computer assisted analysis using the Cornell Ecological Programs, TWINSPAN and DECORANA, demonstrate novel uses of the two programs and their applicability for defining and classifying soil types and "map unit types"--areas of similar ecological characteristics. Detailed data on vegetation, soil and site conditions were collected and analyzed, yielding 17 unique associations of various vegetation species and 9 unique soil types. Further analysis indicated a correlation between vegetation types and soil-elevation-slope positions, but found poor correlation between soil type and slope-elevation. Vegetation and soil types are not deterministically associated, though some trends were evident. Finally, a map of the Turkey Lakes Watershed at a scale of 1:12 000 was produced to show areas of similar vegetation, soil and site characteristics.

251. Winget, C.H.; Addison, P.A.; Rennie, P.J. 1988. Forest effects of long-range transport of air pollution in Canada. In Proc. USSR-Canada Workshop on Airborne Pollutants, April, Thilisi, Georgia, USSR. (CFS-HQ)

Forests cover 4.3 of Canada's 9.9 million ha, fulfilling important roles for terrain stability, wildlife habitat, recreation and flood control. About 161 million ha is productive forest, and the annual harvest of 760 000 ha yields products valued at $31 billion, Canada's largest industry. Adverse climate and soils restrict productivity in the generally semi-natural coniferous forest. Major losses are through fire and pests. Large forest areas--7 million ha on the west coast and 39 million ha in eastern Canada--are exposed to significant regional air pollution, reasonably well documented for sulphate and nitrate deposition, but poorly understood for photochemical oxidants, organics and metals.

Concerns about the impact of regional air pollution on forests have been raised by the public and scientists alike. The observation of forest declines in both maple and birch forests in Canada, and the identification of areas where tree growth reductions have occurred, have emphasized the need for research into the effects of pollution on forest ecosystems. The Canadian Forestry Service (CFS) program aims to quantify regional pollution effects in the forest to assist the government in the development of effective air pollution controls.

The major activities of the CFS program are to:

a) determine the contribution of air pollution to current forest declines (maple and birch) and determine ways to prevent or stop sugar maple stands from declining;

b) determine the pollutant levels that must not be exceeded to ensure the continued productivity and well-being of forests (this information is essential for designing abatement strategies); and

c) determine and monitor forest conditions across Canada to detect future changes attributable to air pollutants and natural stresses in representative forest ecosystems (this serves as an early warning system and a check on the adequacy of abatement measures).

The report describes the nature of the forest in Canada and the decline and growth reductions that have been observed. The research and monitoring programs currently being carried out are also described.

252. Zalshek, E.M.; Puckett, K.J.; Percy, K.E. 1986. Lichen sulphur levels and sulphur deposition patterns in eastern Canada. Water Air Soil Pollut. 30:161-169. (CFS-M)

Marked differences exist between the sulphur and lead concentrations in Cladina rangiferina collected from eastern Canada and the Northwest Territories, Canada. These differences reflected the differing emission/deposition rates in the two regions. The spatial distribution of S and Pb in the lichen from eastern Canada is described in detail. Mean S concentrations ranged from 329 to 959 μg g^{-1}; Pb concentrations varied in the range 3 to 21 μg g^{-1}. A regional gradient in lichen S concentrations was evident with the highest concentrations being found in central and north-central Ontario and the lowest in Newfoundland. A regional gradient for Pb was apparent but was not as well defined as that for S. The regional distribution of S illustrated by the lichen agreed with other indirect measurements of S deposition. Lichen S concentrations correlated with measured wet sulphate deposition.

ADDENDUM

253. Roberge, M.R. 1987. Evolution of the pH of various forest soils over the past twenty years: Effects of stand maturity and acid rain. Laurentian Forestry Centre, Quebec, Que. Inf. Rep. LAU-X-77. (LFC)

The pH of nine forest soils found in the three main forest zones of Quebec--sugar maple, balsam fir, and black spruce--was measured every five years, with some measurements going back to 1961. The stands growing on these soils when the first measurements were taken were all nearly fifty years old and were developing well. Despite the acid rain which has fallen over the past twenty years, the pH of the nine soils has tended to increase. Perhaps there would have been a greater increase in the absence of acid rain; but without control sites or places where no acid rain has fallen, this can only be a matter of conjecture.